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Achievements of Science:

GEOPHYSICS

1962

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Itogi Nauki

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GEOPHYSICS

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FROM THE EDITORIAL BOARD

The present collection of "Achievements in Science" in geophysics comprises reviews on physical, dynamical and synoptical meteorology, climatology, physics of the earth and prospective geophysics. The reviews are prepared according to the materials published in the "Referativnyi Zhurnal Geofizika" in 1962. In individual cases use was also made of abstracts published in the preceding 1—2 years and in the first half of 1963. The review authors set themselves the task of helping the readers of "Referativnyi Zhurnal" to acquire a better grasp of the huge flow of published scientific information and single out the most important scientific results and the greater practical achievements. All the bibliographies in the reviews are given in the form of references to the numbers of the respective abstracts, published in the "Referativnyi Zhurnal Geofizika."

In future it is proposed to issue annually similar collections of reviews of "Achievements in Science" in geophysics according to the materials published in the "Referativnyi Zhurnal Geofizika" in the preceding year. The subjects of the reviews are determined by the editor of the "Referativnyi Zhumal."

Professor A. Kh. Khrgian

PHYSICAL METEOROLOGY

In recent years the study of many physical problems of meteorology took a new path with the use of modern technical devices — satellites, rockets, improved radar methods and balloon sondes for observation of elements such as ozone, chemical admixtures in the atmospheric air, etc. It is not surprising, therefore, that the application of these new techniques made it possible to discover new phenomena in the atmosphere. At the same time, older fields of science, such as the physics of clouds and the investigation of radiation balance, also developed anew.

1. Observations from Satellites

In the period under consideration geophysicists and investigators of the atmosphere gave much attention to data on the weather, particularly to the cloudiness and the temperature of the lower layers of the atmosphere, fronts and cyclones, etc., — information which they succeeded in obtaining by means of meteorological satellites ("Tiros" I, II, III). These observations have become the subject of numerous reviews and popular papers by authors like Frith /1/, Schwarz and Chou /2/, Schnapf /3/, Gobetz /4/, Kletter /5/, Tepper /6, 7/, Mace and Jones /8/ and others unnamed /9—11/. Photographs of cloud systems, obtained from satellites, made it possible to study cyclones, including some of unusual structure, described by Fritz and Wexler /12/, Fritz /13/, and including ring-shaped and spiral cloud belts. Timchalk and Hubert /14/ and Weinstein and Verner /15/ investigated fronts of different intensities from these photographs, and Whitney /16/ investigated convection clouds. The fine structure of cyclone clouds is apparently more clearly observed over oceans. Interesting cases of cellular cloud structure were observed by Krueger and Fritz /17/. In this case not only unstable layers of large extent, connected with comparatively warm ($\Delta T = 8°$) regions of the ocean were found, but, possibly, the influence of wind shear was also observed. The sizes of the observed cells were considerable (up to 35—90 km) and were large compared with their thickness. In this respect they differed from Benar's classical cell model.

It was found that regions of considerable cloudiness coincide usually with warm and humid air "tongues" on isentropic charts. It was also noticed that high-level clouds are apparently sometimes missed by satellites. The forms of clouds and of "cloud roads" made it possible for Whitney /18/ and

Hubert /19/ to draw conclusions on the wind field, including convergent lines and air currents intersecting isohypses. The dimensions of cumulus clouds in this case make it possible to get an idea of the degree of air instability in different parts of cyclones as well as other information. Yamamoto and Wark /20/ and Chapman /21/ discussed the problem of the determination, from a satellite, of the altitude H of clouds from the absorption of radiation reflected from the earth and from clouds in the bands $\lambda = 2\mu$ and $\lambda = 0.76\mu$ (CO_2 and O_2 bands). Observations of the second of these bands apparently promise a higher accuracy in the calculation of H.

Of particular interest for the study of meteorological processes is the determination from a satellite of the temperature of the earth, of the lower layers of the atmosphere and of the upper surface of clouds. This determination is possible mainly by observing the infrared radiation coming from below in the "transparency window" of the atmosphere in the wavelength range from $8-12\mu$ (Hanel /22/, Dreyfus and Hilleary /23/). Although the technique of such measurements, as shown by Nordberg /24/ is still insufficiently reliable and is associated with errors reaching 10%, nevertheless Bandeen et al. /25/, Astheimer et al. /26/, Hanel and Stroud /27/, and Hanel and Wark /28/ have begun the plotting of charts of ascending radiation fluxes. In this connection observations were made both of the influence of large differences in land albedo, and of the influence of the humidity of the lower layer of the troposphere, which lowers the effective temperature of the radiation flux in the indicated "window."

Möller /29/ proposed a method for estimating the humidity of the atmosphere from observations in the spectral band of $6-7\mu$, where absorption and emission are large.

Observations of the infrared radiation also made it possible to detect differences in the temperature of clouds in the front and rear parts of a cyclone. These observations probably furnish a better possibility of distinguishing upper-level clouds than television images in the visible part of the spectrum. They will be useful for the study of cloudiness on the night side of the earth.

For radiational observations, use was made, in addition to satellites, of the "Tiros" series, also of other satellites, as reported by Weinstein and Suomi /30/, who described the use of the satellite "Explorer VII." In /31/ a description is also given of a project of a new meteorological satellite.

Parallel with the development of observations from satellites, the interest in observation and use of data of infrared radiation obtained from ground observation has much increased. New instrument designs for such observations were described by Drummond /32/, and a method of observation of scattered infrared radiation was described by Murcray /33/. Numerous observation series of terrestrial and effective radiation, and of the radiation balance of different regions of the earth, have been collected. We cite the work of Zuev /34/, Poltoraus /35/, Lingova /36/, Hufnagl /37/, Efimova /38/, Lileev /39/, Ovchinnikov /40/ and others. Such investigations have in general been extremely numerous.

One of the important contributions to the direct study of the infrared radiation of the sun was the comparison of the atmosphere's transparency, in the visible and in the infrared part of the spectrum, in the presence of wide contamination of the atmosphere, carried out by Dennis /41/.

Theoretical work on the absorption of solar infrared radiation and the heating of the atmosphere caused thereby also underwent extensive development. As shown by Roach /42/, this heating depends only slightly on the altitude in the layer 1,000—600 mbar, but at the same time varies somewhat with the humidity. Above the 600 mbar level, the heating rapidly decreases as one approaches the tropopause. In general, it is not greater than 1° per 24 hrs. The main role in the heating of the stratosphere is played by carbon dioxide, although Yamamoto /43/ showed that the influence of molecular oxygen may also be appreciable.

As shown by Funk /44/ the agreement between the calculated and observed radiational effects in the lower layers is incomplete owing to the influence of mist not allowed for in the theory. In higher layers of the atmosphere it is satisfactory. A theoretical estimate of the diurnal temperature variation due to radiation gave a value of 0.2° up to altitudes of 20 km and a value of 3—5° at altitudes of 40—50 km.

Goody /45/ again considered the importance of the fine structure of the water vapor absorption bands, determining radiation absorption by the vapor. The absorption and scattering cross-section of water drops for black-body radiation with temperatures from 253 to 298°K was calculated by Stephens /46/.

A calculation of the equilibrium temperature distribution in a stationary atmosphere, made by Manabe and Möller /47/, gave at the level of the tropopause, temperatures 20—40° lower than the observed and, what is more interesting, showed that such a radiational equilibrium sets in extremely slowly (during 200—500 days).

The observations of infrared radiation fluxes in the free atmosphere, in a baroclinic zone of the atmosphere, described by Staley and Kuhn /48/ (for such zones a theoretical calculation is extremely difficult), revealed considerable influence of horizontal inhomogeneities of the atmosphere and of cloudiness. In baroclinic zones considerable variations were observed in the fluxes with altitude, and even radiational heating and cooling, reaching 4—5° per 24 hrs, were observed.

Climatical effects of CO_2 and O_3 emission and consequences of possible time variations in the amount of these gases in the atomsphere were considered by Plass in much detail /49/. It was found that a densification and lowering of the ozone layer may result in appreciable warming (up to 2°), so that ozone may probably serve as a connecting link between variations in the solar ultraviolet radiation and climatic oscillations. The accumulation of CO_2 in the atmosphere, now taking place due to the burning of huge amounts of coal and petroleum, should result in a warming of 1.1° per century, which satisfactorily agrees with observation. In this author's opinion, oscillations in CO_2 in the past could also be one of the causes of the glacial periods.

2. Atmospheric Ozone

Most essential in investigations of atmospheric ozone was the problem of its vertical distribution and circulation, as well as the problem of the methods and results of observation of surface ozone. The vertical distribution of ozone, as reported for example by Ramanathan /50/, was observed by means of ozone zones in Europe, Central Africa and Antarctica. The results of a comparison of chemical and optical ozone zones are described by Paetzold and Piscalar /51/ and Paetzold /52/.

They observed both great variability in the altitude of the ozone layer and in the altitudes of its maximums, and the existence of a fairly large amount of this gas above the 10 mbar level. The observation method, based on the study of the structure of the $\lambda = 9.6\mu$ absorption band, was described by Sheppard /53/, Twomey /54/ and Frith /55/ who analyzed the theory of the observation methods of vertical ozone distribution based on measurement from a satellite of the ultraviolet radiation scattered by the earth and partially absorbed by the ozone layer. A similar idea has been used by Boublil, Blamont et al. /56/, who observed the scattered light of an artificial cloud formed by a rocket at altitudes of 90—110 km in the visible part of the spectrum. In this case well-pronounced Shappyui absorption bands were observed. In the same part of the spectrum ($\lambda = 5{,}900$ and $5{,}250$ Å) photometering on the ground of the artificial satellite "Echo I," carried out by Venkateshwaran /57/, also clearly detected radiation absorption by ozone. It made it possible in this case to find out the vertical ozone distribution and even the existence of its second maximum at an altitude of ~ 55 km. The theory of ozone observation during lunar eclipses, when absorption in Shappyui bands is also clearly noticeable, has been developed by Fesenkov /58/.

The problem of the connection between the ozone content and vertical motions in the atmosphere is of very great interest. Attempts to explain differences in the vertical ozone distribution by vertical motion of different forms were made by Paetzold and Piscalar /59/ and Ramanathan /50/. These attempts, however, have a highly preliminary character. On the other hand, the connection of ozone with the general circulation, with long waves, etc., has been studied in sufficient detail. Thus, for example, Dütsch /60/ observed that the ozone "wave" in January 1958 propagated together with the heat region in the layer between 50 and 10 mbar. Similarly, Boville and Hare showed /61/ that the sharp ozone minimums in February 1959 and in January 1960 were connected with cold cores in the stratosphere. The motion of ozone in "long waves" in the lower stratosphere was studied by Gushchin and Romanova /62/ and the connection of ozone with jet currents and with the position of the tropopause was considered by Gushchin /63/. He found that a jet stream increases the amount of ozone. The meridional ozone circulation and its connection with synoptical types was considered by Paetzold and Piscalar /59/, Ramanathan /50/, Khrgian and Kuznetsov /64/, Fea /65/, Mattana, Sana and Serra /66/, Van Gui-chin' and Gushchin /67/. Gushchin and Romanova /62/ gave estimates of the coefficient of macroturbulence of the terrestrial atmosphere, based on data on the variability in atmospheric ozone. These estimates gave values of $10^6 - 10^7$ m^2/sec.

In a number of countries methods have been developed for observing the ozone concentration in the surface layer of the atomosphere. The works of Kiveliovich and Vassy /68/, Britaev /69/, McKee /70/, and Kroenig /71/ were all devoted to them. Along with these observations estimates were made of the vertical ozone transport in the lower layers and the "runoff" intensity, i. e., its absorption by the terrestrial surface, reaching $6 \cdot 10^{10}$ molecules/cm^2sec. Direct observations of ozone concentration were extended also to the troposphere, in particular in the mentioned work of Kroenig /71/. The latter conducted observations by means of air balloons. Concentration determinations also made it possible to estimate the coefficient of vertical turbulence (10^5—10^6 cm^2/sec) and even to observe the existence of air exchange between the troposphere and the stratosphere. A number of harmful effects of the ozone of the surface atmospheric layer on plants was described by Wanta and Moreland /72/. Britaev /69/ expressed the opinion that the ozone of the lower layers may come from the stratosphere, whereas in the opinion of Kroenig and Ney /71/, the ozone in the lower atmosphere forms during thunderstorms and also nuclear explosions.

3. Radiolocation of Clouds and Precipitation

In recent years new radar methods, in which Soviet scientists have played a very large part, have been developed for the study of clouds and precipitation. New designs of airplane radar have been used : AN/CPS-23, AN/CPS-45 and others (/73, 74/, Nagle /75/, Schatzle and Chronise /76/), and also a constant-altitude plan position indicator /77/. Observation of solar radio emission on millimetric waves was proposed by Wijnberg and Bogan /78/ for estimating the total amount of precipitated water in the atmosphere etc.

The old technique of estimating the precipitation intensity R from the reflectivity Z of a radiosignal by means of the empirical equation $Z = AR^n$ was improved by a number of authors — Muchnik /79/, Markovich et al. /80/, Imai /81/. The use of a variable-intensity signal for this purpose was described by Katz /82/ and the observation of the signal attenuation in the precipitation region was also used by Collis /83/ for estimating its intensity. At the same time Borovikov, et al. /84/ discovered that the liquid-water content w of a cloud cannot be determined from the reflectivity Z without taking into account the presence of large drops, which give a small contribution in w and a large contribution in Z. This is obviously a great difficult at present in the radar determination of precipitation intensity.

Radar observations gave the possibility of describing in detail many typhoons with the remarkable phenomenon of "gale eye" and with spiral belts of strong precipitation forming and dissolving in them, as was done by Bigler and Hexter /85/, Senn /86/, Senn and Hiser /87/ and others; Ligda /88/ also observed gales with similar spiral belts, but without a "gale eye" and without such a sharp drop in pressure in the center as in the typhoon. Ramsey /89/, Changnon /90/, Kessler /91/, using such a method, studied cold fronts and squall lines which give, as shown by statistics, for example in the USA, up to 66% of all liquid precipitation.

Radar observations, made by Donaldson /92/ showed that during gales, and in particular during whirlwinds and tornadoes, the related Cb clouds are the highest and thickest, and the precipitation regions in them, seen on the screen, sometimes extend to altitudes of 15—16 km. In this case the reflectivity reaches 10^6—10^7 mm^6/m^3, although Harger and Warden /93/

give a somewhat smaller figure: $Z = 2 \cdot 10^5\ mm^6/m^3$. The liquid-water content in individual sections of such clouds possibly reaches $10-20\ g/m^3$. In contrast to these authors, Stout /94/ assumes that even during whirlwinds the altitude of the cumulus-nimbus is not larger than 6 km.

The observation of thunderstorms by continuous scanning of the whole sky, carried out by Moore, Vonnegut et al. /95/ showed in particular that after each lightning strike a region of strong reflectivity with $Z = 2 \cdot 10^5 - 10^6$ appears in the cloud. This region then descends at a velocity of up to 60 m/sec; reaching the surface, it there gives rise to a shower of tremendous intensity of up to 100 mm/hr. Shackford /96/ also studied the structure of lightning by using radar.

A comparison of the theory of the formation of precipitation in Cb with the images on the radar screen showed that the increase in Z in natural conditions (Todd /97/) is considerably slower, and in the case of artificial effects faster, than predicted by the simplified theory.

Much work has been spent on the theoretical calculation of the reflectivity or of the effective cross section σ of individual snow, hail, rain and wet ice particles, which create, as is known, a "bright line" on vertical radar sections. Stephens /98/ made these calculations for ice and water spheres for wavelengths from 0.43 to 23 cm and for values of the parameter $\alpha = 2\pi r/\lambda$ from 0.1 to 5. In individual cases, for a number of narrow intervals of the values of α, an increase of a resonant character in σ was observed in this case. Atlas and Ludlam /99/ found that for $\alpha > 6$ dry hail reflects much stronger than hail moistened from the surface, and that observation of hail is almost no longer possible on wavelengths of 4.7 cm and more. For spheres large compared with λ the value of σ was calculated by McDonald /100/. Experimental determinations of σ were made for $\lambda = 3.2$ cm by Gerhardt, Tolbert et al. /101/. These authors observed large ($d = 2-7$ mm) drops and large ($d = 3-35$ mm) hail. Up to drops of $d = 3.5$ mm the observed σ was larger than the calculated, and for $d > 3.5$ mm both were in good agreement, and so also in the case of dry hail. Moist hail of small size reflected as water drops. These investigations of the same authors were then continued with wavelengths of 1.5 and 5.72 cm /102/.

An entirely new approach to the study of the spectrum of drop sizes, from the magnitude and spectrum of the fluctuations of the reflected signal, was described by Gorelik and Smirnova /103/. The mean drop radius was estimated by the method of these authors fairly accurately in their first experiments.

Of great interest for the physics of the atmosphere are radio-reflections from cloudless atmosphere, sometimes called in foreign literature "angels," in our literature more appropriately "thermics," and caused either by atmospheric turbulence or by convection. For their observation Conover /104/ proposed new types of radar amplifiers (with a low noise level). Chernikov /105/ described the results of observations of thermics by means of an upward directed antenna with a diameter of 20 m on 3.2 cm wavelength. Thus, he succeeded in demonstrating that the reflection is from regions with a diameter of 2—3 m and with a radius of curvature of the reflecting layer or surface of 100—200 m. Annular-shaped echoes of the same type as the thermics described above were observed by Kulshrestha in India /106/. There Rai /107/ also observed echoes in the form of elongated undulated bands, observed at small elevation angles over the horizon — from zero to 2°. They probably were caused by air waves which arose, for example, in under-inversion layers in the lower atmosphere. A theoretical analysis carried out by Rai /108/ forced him to assume that thermics are caused by reflection from some cylindrical, not spherical, formations in the atmosphere or by reflections from long chains of cells.

A new chapter in the application of radar to the study of the atmosphere was opened with a new method of observation of the velocity of ordered and turbulent motions in the atmosphere, based on the Doppler principle. It was described, in particular, by Probert-Jones /109/ and Boyenval /110/.

A new and important field of atmospheric optics (as well as of the chemistry of the atmosphere) is the study of stratospheric aerosol. This aerosol may be of cosmic or terrestrial origin. Recently it has become clear that it has a significant effect on the optical properties of the upper layers of the atmosphere (up to altitudes of 70—90 km) and at the same time is a source of condensation nuclei for the lower layers of the atmosphere.

Direct observations of aerosol particles, made by Wright and Hodge /111/, detected in the layer 12—26 km particles of a clearly meteoritic origin with a concentration of $\sim 3\,m^{-3}$. This agrees with the number of stratospheric particles observed to settle in the Arctic at the rate of $\sim 1\,cm^{-2}$ per day. The data of another series of observations in the stratosphere, by means of impact counters with silicon oil lifted by balloons and airplanes, continued over a whole year, and were described by Junge /112, 113/ and Chagnon and Junge /114/. They detected a layer of large vertical thickness in the stratosphere, containing particles with a radius from 0.1 to 2 microns, on the average 0.15 micron in the layer 15—23 km. This layer is fairly permanent and apparently covers the whole planet, since the observations of the authors mentioned detected it at latitudes from 40° south to 70° north. Only the smallest of these particles, with a radius of 0.1 micron, can be considered as carried directly from the troposphere. At the same time, their high content of sulfur, detected by chemical analysis, does not make it possible to consider them, for example, extra-terrestrial meteoric particles. They form possibly by the oxidation of the gases H_2S and SO_2, which penetrate from the troposphere below, or by ozone or oxygen in the presence of ultraviolet radiation.

Optical observations conducted by means of a photomultiplier with light filters, mounted on the rocket "Veronique" (Rössler and Vassy /115/ and Rössler /116/), detected a considerably higher intensity of diffuse light in the stratosphere as compared with that which would result from simple molecular diffusion. The ratio of the observed to the theoretical molecular diffusion, lowest over the tropopause, reaches a maximum at an altitude of 22 km and remains high up to 50 km. In another series of observations, considered by Mikirov /117/, aerosol layers were observed at altitudes of 85—92 km, close to those at which luminous clouds are observed.

The problem of luminous clouds thereby appears in a new light since, in their case, investigation of the micro-structure by optical methods becomes possible. At the same time there arises a problem of condensation nuclei, which may give the beginning of cloud particles.

From observations of the near-solar halo, Eddy /118/ attempted to determine the spectrum of sizes of stratospheric particles in the layer from 12 to 24 km. This spectrum apparently is more uniform in the upper than in the lower part of this layer. Friedlander /119/ attempted to explain the striking similarity of the spectrum to that observed in the troposphere by considering processes of aerosol coagulation, using for this the kinetic equation and an analysis of the dimensions of the quantities involved.

As we have repeatedly seen above, a great many problems of physical meteorology — observation of the earth from satellites, optical properties of the atmosphere, development of radar methods of study of the atmosphere, etc. — are closely related to the physics of condensation processes. The great attention which geophysicists give to the physics of clouds is therefore clear. The literature on this subject is very rich, particularly in the USSR. The physics of clouds is of tremendous practical importance for aviation, weather forecasting, agriculture and other purposes. Investigators have been able, on the one hand, to penetrate very deeply into the essence of the physical phenomena of condensation, coagulation, etc., and on the other hand, to study the large-scale synoptical processes and forms of motion of the atmosphere favorable to them. For the first time in science, the physics of clouds resulted in feasible methods of affecting the atmosphere. We therefore give a review of Soviet works on this problem, somewhat widening the framework and period of our review and covering partially 1959—1961.

4. Physics of Clouds.

The investigation of clouds has been carried out in our country in a number of directions. A general idea of its scope is given in the monographs "Physics of Clouds" of Borovikov et al. /120/; "Artificial Effects on Clouds and Fogs" of Nikandrov /337/ (both works are mainly devoted to the micro-structure of clouds and its observation); "Investigations in the Physics of Coarsely Dispersed Aerosols" of Levin /338/; "Instruments and Technique of Cloud Investigation from Airplanes" of Zaitsev and Ledokhovich /121/, as well as the monographs of Vul'fson /122/ and Nelepets and Stepanenko /339/, partially devoted also to methods and results of observation in clouds.

One should also mention the monographs on glazed frost by Buchinskii /123/ and Rudneva /124/, many theoretical and practical aspects of which are close to the problems mentioned above.

A number of works reflecting the state of the problem were published in the form of a collection of papers of the interdepartmental conference of 1959 under the heading of "Investigations of Clouds, Precipitation and Thunderstorm Electricity" (Publishing House of the Academy of Sciences of the USSR, 1961).

The study of clouds required first of all improvement in the former microphysical methods and at the same time the development of new methods of macrostructural observation both by the method of photogrammetry and filming, and by the radar method.

For microstructural observations Starostina and Chudaikin worked out new variants of traps and impact counters /125, 126/, which were also used on balloon sondes /127/. Aleksandrov and Petrenchuk /128/ also proposed an instrument for taking samples of cloud drops. Korneev and Trubnikov /129/ and Malkina /130/ used the method of replicas for the observation of drops and crystals, and Levin /131/ and Kazanskii and Levin /132/ developed in detail the theory of capture of drops by traps of various types. This theory has very important generalizations and is applicable to other fields of the physics of the atmosphere, e.g., the study of airplane icing and measures for its prevention.

On the other hand, the capture theory has already made it possible, in a number of cases, to study the mechanism of precipitation formation by drop fusion. The process of fusion in the presence of electric charges on the drops was studied by Levin /133/.

Improvements in the method of determining the liquid-water content of clouds were described by Zaitsev and Ledokhovich /134/. Balabanova proposed a new method for measuring the liquid-water content by means of filters /135, 136/. The idea of a direct determination of the statistical characteristics of an aggregate of cloud drops was proposed and worked out by Kozlov /137/, and the properties and variability of such an aggregation were considered by Mazin and Skosyreva /138/.

Optical methods for investigating the microstructure of clouds have not been given much attention recently. The approach to the solution of such problems was indicated by Shifrin and Golikov /139/, and to investigations of the micro-structure of rain, by Polyakova /140/. Zabrodskii and Morachevskii /141/ described an instrument for measuring the transparency coefficiency in clouds, which has already made it possible to collect considerable material, and in particular, to show that in St-Sc clouds the meteorological visibility range varies within 200—300 m, and in Ns-As clouds, within 100 and 200 m. Rovinskii /142/ proposed a chemical method of recording cloud drops, which makes it possible to estimate their salinity as well as their size.

Since in recent years the interest in the study of the macrostructure of clouds has again increased, the technique of such observations has also begun to improve.

To measure their altitudes, Kogan-Beletskii proposed some improvement in the method of aerial observation /143/, and highly approximate computational methods were given by Il'in /144/ and Dubrovin /145/. A new pulsed light altimeter, recording and allowing the estimation simultaneously of both the density and the general structure of clouds, was also proposed by Bozhevikov /146, 147/.

Bibikova /148/, Dyubyuk /149/ and Balabuev /150/ developed new variants of the photogrammetric study of clouds, their forms, spatial positions and motions. This included different problems of the technique of the kind of observation and study of luminous cloud, dealt with by Burov /151/ and Dirikis and Frantsmanis /152/. These investigations have already led Dyubyuk, Petruchuk and Trubinova /153/ to some conclusions concerning the mechanism of convective motions in the atmosphere. The method of observing clouds of the "whole sky" was also systematically used.

The radar-detection method was improved by Shupyatskii and Morgunov /154, 155/ for observing the form of solid cloud particles. The precipitation distribution over area and the liquid-water content of clouds were studied by, besides Shupyatskii /156/, also Borovikov, Kostarev and Mazin /157, 158/, and by Noronets /159/ mainly by greatly increasing the power of the installation. For the same observations Kostarev /160/ used a standard target (Sal'man /161/). These installations made it possible to observe also the fine structure of clouds, including cirrus, connected often with belts of falling precipitation (snow).

After radar methods had been proposed and realized for observing wind gradients and shears and, in general, velocities in clouds, Gorelik and Smirnova /162/ succeeded in separating the downward vertical component of the motion, to estimate from the spectrum of the falling velocities the spectrum of the sizes of cloud drops, at least of the larger ones. But the newest and most promising approach was the idea of observing turbulent motions in clouds, developed by Gorelik, Mel'nichuk and Chernikov /163, 164, 165/. These motions characterize both the behavior and the formation processes of clouds.

Although investigations of the microstructure of clouds have long been carried out in the USSR and have already made it possible for Borovikov and others to collect considerable material /120/, the work has continued during the last few years (Dyachenko /166/). The applicability of different distribution functions of drop sizes have been discussed by Voskresenskii and Dergach /167/; Dergach /168/, Laktionov and Levin /169/, Nikandrov /170/, Sovetova /171/, Khimach and Shishkin /172/ collected data on the parameters of this distribution in clouds of different forms, etc.

A new detailed study was undertaken by Borovikov, Mazin and Nevzorov /173/ on the microstructure of the larger-drop fraction of clouds, whose concentration is low but is important for understanding the process of precipitation formation. Such particles are situated in a cloud as though in individual regions, and their number rapidly decreases with increasing radius approximately by an exponential law. Minervin /174, 175/ collected extensive material on the liquid-water content of clouds. Numerous observations of the form of ice crystals in the atmosphere, including transitional forms from crystals to frozen drops, were conducted by Klinov /176, 177, 178/, who succeeded in successfully associating the form of crystals with the optical phenomena caused by them.

For the first time people have succeeded in collecting numerous observations of condensation nuclei at the network of stations created for the International Geophysical Year, and Dergach /179/, Dmitrieva and Kholodova /180/ and Selezneva /181/ have succeeded in studying both the geographical and the vertical distribution of the nuclei, whose theory was given by Selezneva and Yudin /182/. It has been found in this connection that the exponential distribution of nuclei over altitude is as though made up of two components, possibly connected with two types of nuclei. Although Belyaev described a new mechanism of salt transport from the sea surface and of the formation of such "marine nuclei," the distribution of the latter and their relation to the closeness of an open sea surface were found to be much more complicated than was earlier supposed.

Connected with the problem of nuclei and their composition is the problem of the structure of precipitation water, also studied in detail during the International Geophysical Year parallel with similar works in other countries (Czechoslovakia, Scandinavia and elsewhere). It was found that cloud particles, particularly snow flakes, capture solid nuclei from the atmosphere. Near sea coasts, the concentration of chlorides in precipitation is considerable, but on the continent, in the southern part of the European territory of the USSR, their amount is also high, as shown by Drozdova, Petrenchuk and Svistov /183/, Petrenchuk and Selevneva /184/ and Selezneva /185/. Particularly high increases were recorded in the amount of sulfates precipitated, appearing in large amounts in industrial smoke.

The problem of airplane icing, depending on the microstructure of the clouds was more accurately defined in the calculation of the water freezing process itself. Some observations of Voskresenskii and Chukanin /186/ also supplemented our ideas of the icing mechanism, in particular the attenuation of icing in mixed clouds, and also established the connection between the microstructure and the character of the forming ice. Ice forecasting was included also in the general synoptico-aviational forecasting. Prokhorenko and Raevskii /187/ and Raevskii /188/ studied glazed frost, which is similar to some extent to icing. They observed that in surface layers of the atmosphere, sublimation, that is formation of rime, is observed more frequently than in the free atmosphere.

The problem of the macrostructure of clouds, in its connection with air currents of medium and large scales, became increasingly prominent in the period under consideration.

Stratus clouds (St, Sc), often strongly disturbing aviation and not easily forecast, have been the subject of many works. Their theory, describing turbulent mixing in the boundary layer of the atmosphere, was developed by Kozharin /189/ taking into account advection and turbulent heat conduction, also, in a particularly detailed form, by Matveev /190, 191/. Later, Matveev /192—194/ also took into account vertical motions and showed that, in this case, the liquid-water content and its rate of growth in the cloud increase with altitude with increasing ratio of the coefficient of turbulence to the vertical velocity.

We note incidentally that Abramovich and Khrgian /195, 196/ showed in a number of works that the turbulence, estimated by means of the Richardson number Ri, and the advection of warm air, strongly affect the formation of St-Sc clouds. This effect depends mostly on advection at the level 300 or 600 m over the terrestrial surface, as shown by Kolokolova /197/.

In another group of theoretical works Feigel'son /198—202/ considered radiational cooling (and heating) of clouds taking place simultaneously with turbulent mixing. She estimated in this case the rate of the radiational temperature drop, reaching 4° per 30 min at the upper cloud boundary. The cooling of the cloud on top leads to a loss of stability and to further condensation. The liquid-water content of the cloud may rise in this case from 0.5 to 1.7 g/m^3 during 30 minutes to a value favorable for the formation of appreciable precipitation. An example analyzed by Gogoleva /203/ shows that strong radiational cooling of air, initially cloudless, may also lead to condensation.

A number of statistical investigations by Dergach, Zabrodskii and Morachevskii /207/, Dzhuraev /208/, Dragun /209/, Verbitskaya /204/, Gigineishvili and Nikolaishvili /205/, Gromokovskii /206/ were devoted to the altitude of the boundaries of St-Sc clouds. It was shown, for example, that the lower boundary of St rises from north to south from 0.20 km over the Arctic to 0.52 km in Baku and 0.80 km in Alma-Ata. The lower boundary of Sc also rises accordingly. Voskresenskii and Chukanin /186/ also observed an increase in the liquid-water content of Sc over the open sea as compared with the continent.

Aerological profiles presented by Abramovich and Khrgian /195/, showed that the highest dynamical instability, giving birth to low clouds, exists in the lowest layer of the atmosphere (up to 50 m) over the terrestrial surface and that variations in the degree of instability are associated with variations in cloud altitudes. It was found in these studies that the Sc layer descends when an inversion "covering" it descends and that clouds disappear when the inversion base descends below the condensation level in the under-inversion layer. The influence of warm air advection on the formation of low clouds in mountainous country was studied by synoptical and theoretical methods (Shekhtman /210, 211/). The most detailed investigation both of the statistics of the altitudes and frequency of low stratus clouds, and also of the conditions of their formation during advection from sea under the complicated physico-geographical conditions of the Far East, was carried out by Il'inskii /212/. A number of forecasting rules obtained in different works was summarized in the "Collection of procedural instructions in aviational meteorology" (TsIP* 1959).

The works of Sovetova /213, 214/ are devoted to the macrostructure of frontal clouds. In the second of these works the attenuation and descent of cloud front systems during motion over the plains of West Siberia from west to east, and the increase in their thickness when approaching Altai, is considered. Baranov also showed /215/ that frontal cloudiness in 50—60% of the cases consists of two or more individual layers, particularly near the front line. Burkovskaya /216, 217/ found that the liquid-water content of clouds in the front zone is on the average distributed as the velocity of ascending motion, calculated by Ruzin /218/ from Dyubyuk's theoretical model for the front zone. Underfrontal clouds appear, forming from the vapor of evaporating precipitation drops, as shown by Tsitovich /219/, owing to increased dynamical instability in the surface air layer, although this layer is thermally stable.

Recently attention was drawn both to processes taking place on the upper boundary of cloud layers, to the topography of the latter and to the possibilities of forecasting their altitudes.

The technique of studying the topography of the upper boundary of frontal clouds was considered by Bugaeva and Romanov /220/. Nepovitova /221/ showed that an increase in the temperature gradient in a cloud near its upper boundary causes there the development of convection of the cellular type, and Zaitsev and Ledokhovich /121/ observed that in such cells there are periodical (in space) temperature variations of ±0.4°, and sometimes even up to 2.4°.

The primary elements of convection, "thermals," have been detected by means of radar and also by means of a sensitive airplane thermometer, observations by which were conducted parallel to observations by an accelerometer, as was done by Vul'fson /222, 223/. Novozhilov /224/ suggested a hypothesis according to which the first impulse for the development of convection is given by medium-scale waves ("mesowaves"),

* [For this and other abbreviations, see Explanatory List on Page 130.]

and Selezneva and Churinova /225/ ascribe the same role to the large vertical gradient of the wind velocity in the boundary layer. Novozhilov /226/ also assumed that strong turbulence, destroying convective jets, hinders the formation of cumulus clouds. According to Vul'fson /227/, a cloud once formed draws in jets coming from the surface of the earth, and D'yachenko /228/ assumes that a descending motion and some above-cloud circulation arises over a cloud. The motion inside a Cu-cong strongly developing in altitude was described by Shmeter /229/, and the dynamics of smaller CU by Vul'fson /227/.

Observations of Dergach /230/ showed that both the temperature gradient and the vertical velocity in a cloud, above some level, decrease with increasing altitude. Bibilashvili, Zaitseva, Kuz'min, Lapcheva, Ordzhonikidze, Sulakvelidze in a number of joint works /231—234/ developed a theory, based on this fact, of the formation of shower pr precipitation taking into account coagulation processes. This theory predicts the possibility of the existence of very large liquid-water content in convective clouds (up to $40\,g/m^3$), but observations published by Chuvaev /235/ indicate liquid-water content not higher than $1.5\,g/m^3$.

Chuvaev /236/ showed that crystallization, putting into operation the mechanism of recondensation, of the formation of soft hail, of large snow flakes and drops in Cu, was found to be strongest at temperatures from −21 to −35°. It has been shown in this connection that even on the south of the USSR Cu-cong clouds in most cases reach the crystallization level.

The works of Pavlovskaya /237/, Selezneva /238/, Selezneva and Churinova /239/ were devoted to the analysis of the aerological conditions of development of convective clouds. A number of theoretical investigations of this problem, using mainly the "layer method", were published by Shishkin /240, 241/, who indicated, in particular, some ways of forecasting convective clouds.

Much attention was given to the synoptical conditions of convective cloud formation, a fact which manifests the growing general interest in macrostructural investigations. Khromov /242, 243/ described the conditions for the appearance of tropical fronts. Gigineishvili /244/ and Guniya /245/ considered the influence of a broken and mountainous terrain on the development of convection phenomena. For the same purpose Shekhtman /210/ used hydrodynamical considerations. The synoptical conditions for the formation of thunderstorm clouds in Tadzhikistan were considered by Deminev /246/, in the Omsk region by Erofeeva /247/, in the Leningrad region by Novikov and Sergeeva /248/, etc.

Cirrus clouds. Observations of cirrus cloud forms, processed by Zamorskii /249/, Minervin /250/, Khrgian /251/, Chichikova /252/ and others, showed that many condensation processes, similar to those producing low clouds, for example stratus clouds, take place there. These processes are connected with turbulence, convection and waves. As assumed by Minervin /250/, as a result of the disintegration of a Sc layer (similar to St) belts of cirrus clouds, Ci-trails, form. The dependence of the form of the trails on the wind shear was studied by Mazin and Skosyreva /253/. This form indicates the presence inside Ci of fairly large crystals. The liquid-water content of these clouds, estimated both by the usual methods and from the attenuation of solar radiation, was found to be very low, $0.002-0.004\ g/m^3$.

A statistical processing of the altitudes of Ci-Cs boundaries, performed by Baranov /254—257/, confirmed that these clouds are usually situated below the tropopause. Their thickness increases with the rise in the tropopause (and with the fall in its temperature). Zak /258/ showed that they rarely descend below 5 km, although sometimes cirrostratus transform directly below into a system of Ns-As at altitudes of 3—5 km. On a synoptical map the zone of cirrus clouds is particularly wide at an occluded front in summer, and their thickness is particularly large in winter, as follows from the paper of Zak and Chernega /259/. Contributing to the appearance of Ci-Cs are general ascending motions with velocities of the order of 3 cm/sec at levels of 300—500 mbar and heat advection at levels of 200—300 mbar.

The opinion is also expressed by Fedorova /260/, that in many cases cirrus clouds are not connected with fronts existing at the given moment, but formed at fronts already long disintegrated. Aeroclimatological processing of observations conducted in the Kazakh SSR made it possible for Chichinova /252/ to show that local maximums of the frequency of Ci and Cs are connected with zones of intensified cyclonic activity either over the south of the Caspian Sea, or over the south of Central Asia, and with the influence of mountains both high and low. According to investigations of Fedorova /261/, the motion of large (up to $3 \cdot 10^6$ km^2) fields of Ci-Cs is determined both by the wind approximately at the 300 mbar level, and by the development (propagation) of these fields in cyclonic clouds.

Driving /262, 263/ described very thin clouds of very low density with a liquid-water content of the order of $(1-2) \cdot 10^{-5}$ g/m^3 and with a concentration of drops of 6—11 cm^{-3}, observed several times at night at great altitudes (20—25 km) by means of a projector.

L u m i n o u s c l o u d s. The extensive system of observation organized in the USSR during the International Geophysical Year enabled Gromova /264, 265/, Sharonov /266/, Pavlova /267/ to collect detailed statistical data on luminous clouds. Grishin /268/ and Lebedeva /269/ described their form and motion in several examples, and Grishin /270/ also attempted to analyze the synoptical conditions of the formation of luminous clouds. Sharonov /271—275/, Sytinskaya /276/ and Vasil'ev /277, 278/ spent much effort in organizing and processing photometric observations of luminous clouds, in particular for estimating the concentration of matter in them and for estimating the conditions of their visibility. Bronshten /279/ considered the problem of the temperature of their particles. Khvostikov /280, 281/ developed the hypothesis of the "ice nature" of luminous clouds, for which he got the support of Bronshten /279/ who pointed out that cosmic dust may also exert an indirect influence on vapor condensation in the upper atmosphere.

O r o g r a p h i c c l o u d s. Statistical investigations of Khrgian /282/ showed that broken terrain and mountain ridges like the Ural increase the cloudiness on the windward side and sharply reduce it on the lee side, in particular in winter. Thus, behind the Ural the probability of an overcast sky in winter decreases by 21%, while the probability of a clear sky increases by 14%. Musaelyan /283/ also observed that on the lee side of mountains Ac lent and similar forms are much more frequently observed than on the windward side. An example of this is the highest southern and northern parts of the Scandinavian range. As observed by Dyubyuk, Bibikova and Trubnikov /284/, banks of Ac lent are situated parallel to the ridges, as for example the Ac banks observed behind the Ai-Petrinskaya Yaila, which are separated by an interval of 8km and which appear at night and disintegrate by day. These observations showed that the influence of mountains with an altitude of only 1.1km extends to an altitude of up to 4.5km. The development of individual lenticularis clouds over mountains of the Far East was described by Arkhangel'skii /285/, over the Crimean mountains-by Dyubyuk /153/ and so on.

Most important for the theory of orographic clouds, in addition to the monograph of Musaelyan, "Barrier Waves in the Atmosphere," is the work of Trubnikov /286/, where for the first time the equations of flow around uneven relief were solved simultaneously with the equations of transport and condensation of water vapor. It was shown that among the series of harmonics the most intensive waves have a length of about 10km, that condensation somewhat reduces the wave amplitude and shifts the position of the cloud and creates a lag with respect to the wave crest.

As regards other local clouds, cloud banks connected with sea breeze were described by Dyubyuk /153/, Novozhilov /287, 288/ and others.

Electricity of clouds. Here the most important problem is to explain the charges of clouds and the origin of thunderstorm electricity. Numerous observations of the charge of drops of fog, cloud and rain were made by Katsyka and Makhotkin /289/, Krasnogorskaya /290/, Makhotkin and Solov'ev /291/ Petrov /292—294/, Pudovkina and Katsyka /295/ simultaneously with a determination of the drop sizes. A considerable decrease in the number of light ions in cloud and in fog has been observed which speaks in favor of the diffusion charging mechanism. However, drop charges are often larger than those which can be created by such a mechanism /294/. From observations of Sergieva /296/, the number of charged drops in a cloud increases with time, but the dispersion in the charge values is all the time very large. The charge sign apparently depends on the prevalence of negative or positive conductivity. The same author found that stratus-like clouds may be neutral, although Dvali /297/ observed the prevalence of a negative charge in them.

Along with direct charge determinations, Dvali analyzed, like Philippov /298/, data on the electric field at the surface in the presence of clouds. Imyanitov /299/ observed the field directly in the cloud during a flight in an airplane. Surface observations indicate appreciable, but variable charges in stratonimbus clouds and small, field-reducing charges in St—Sc. Such observations make it possible to estimate the charges in shower clouds Cb. Airplane observations of Imyanitov indicated a "chaotic" or turbulent structure of the charges in thunderstorm clouds, but with a prevalence of positive charges in the upper and negative charges in the lower part of the cloud.

Artificial modifications of clouds. The problem of artificial modification of clouds was investigated in detail in the period under consideration, as shown by the review papers of Gaivoronskii /300/ and Sulakvelidze /301, 302/. Tverskoi /303/ considered modification by means of sound, Lebedev and Aleksandrov /304/ studied the effect of wettable particles, and Krasikov /305, 306/ of colloid solutions. The greatest attention was given to the use of CO_2 and AgI. Balabanova, Zhigalovskaya and Maleev /307—309/ studied methods of creating a thin AgI aerosol and processes of destruction of its particles at high temperatures. Vernidub et al. /310/ considered the use of lead iodide. A mechanism of the effect of silver iodide was studied by Balabanova /311/, who also considered the influence of temperature on this process, which is sometimes considered insignificant if the de-activation of the particles by solar radiation is excluded. According to Balabanova's data, the minimum effective concentration of AgI particles is 10 cm^{-3}, and the maximum useful is 1500 m^{-3}, after which its increase does not affect the "yield" of ice particles. In the first case the amount used is only 100 g/ km^3 of cloud. Experiments in a fog chamber, described by Aksenov and Plaude /312/, with "vapor" and "pulverization" fog showed that the probability of drop freezing upon collision with AgI nuclei is low and, as verified by Plaude /313/, the mechanism is mainly sublimational.

Investigations of the use of solid carbon dioxide (dry ice) in various natural conditions were continued by Gaivoronskii and Seregin /300, 314 — 316/ and by Morachevskii and Nikandrov /317/. It was possible in this case to estimate experimentally both the necessary amount of CO_2 as dependent on the cloud thickness and the time necessary for achieving the maximum effect (for example 12-16 min in the case of clouds more than 300 m thick), and the lifetime of the crystalline zone in the cloud (70 minutes in the case of a wind of 50m/sec and less in the case of higher velocities).

Nikandrov /318/ developed a theory of the association of the molecules and of the primary formation of ice nuclei near cold CO_2 particles. Much attention was given to the spread of nuclei in a cloud and to the calculation of the possible area of influence. For such calculations Krasnovskaya /319, 320/ used the theory of turbulent diffusion and found that the velocity of spread of the nuclei is 1m/sec (in satisfactory agreement with the experiment) and that after 25 min the spreading lags behind that predicted by the theory. The problem of the crystallization of a system of supercooled drops was considered in a more general form by Belyaev /321—323/, Belyaev and Kolesnikov /325, 326/, and their results were in general confirmed by the experiment of Belyaev, Gaivoronskii, Kolesnikov and Krasnovskaya /327/ in natural clouds.

A number of investigations have been devoted to the use of artificial modifications of hail clouds with the purpose of preventing hail damage, rather than its localization. This problem was analyzed by Balabanova et al. /328/, Gaivoronskii and Seregin /316/ and Nikandrov /329/. The efficiency of such a modification depends on the synoptical conditions — on the presence of frontal or local storms and on the properties of the individual clouds subjected to the effect. But /330/ also set the problem of possible modification of frontal clouds, which is difficult from the microphysical point of view, but favorable with respect to the large moisture reserve in the clouds and the rapid renewal of this reserve, particularly in mountain conditions. Belyaev and Pavlova /331/ showed that artificial scattering of clouds, changing the radiation balance, may thereby affect the general synoptical process.

The modification technique was studied both from an airplane, and by means of small rockets recently developed and described by Gaivoronskii /316/. When rockets are used it is necessary, as shown by Kostyanitsin /332/, to take into account the loss of CO_2 which evaporates, partly unproductively, in the blast wave. Balabanova and Vyadrov /333/ studied the problem experimentally of the use of ascending air currents, of pilot balloons and of airplanes for "throwing" reagents into convective clouds. Voskresenskii and Morachevskii /334/ described airplane equipment for the formation of a silver iodide haze, and Krasnovskii /335/ and Shmel'kov /336/ described an instrument for preparing CO_2 granules from liquid carbon dioxide transported in balloons, and for dosing the cloud seeding with these granules.

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Professor A. S. Monin

DYNAMIC AND SYNOPTIC METEOROLOGY

1. General Circulation of the Atmosphere and Long-Range Weather Forecasting

During the last few years, as a result of the investigation of the factors which limit the effective time of numerical short-range weather forecasts, the accumulation of empirico-synoptic data on the nature of large-scale atmospheric processes, and the completion of the first numerical experiments of setting up models of the general circulation of the atmosphere in dynamic meteorology, a solution to one of the major problems has been brought nearer.

This is the physical explanation of long-range weather anomalies and the forecasting of such anomalies. A number of works, reviewed in "Referativnyi Zhurnal Geofizika" in 1962, are devoted to this very important subject.

A discussion of the various scientific aspects of long-range weather forecasting is contained in the papers of Sutcliffe /1/, Sutton /2/, Bolin /3/. Sutcliffe /1/ notes that the current methods of long-range forecasting, in particular the method of analogs, do not provide the necessary accuracy He also believed that tele-filming of world weather by means of artificial satellites of the earth might give good data for long-range forecasting. In paper /2/ the opinion is expressed that the state of the atmosphere, averaged over a long period, should be independent of its initial state, and a method of temperature analogs developed in Great Britain is reported. In paper /3/ the importance of allowing for external (non-adiabatic) factors (heating, friction) in forecasting atmospheric processes on a planetary scale is pointed out.

It is now already clear that in long-range weather changes there are adiabatic processes connecting the atmosphere with its surrounding environment (that is, in the first place, with the underlying surface). This also determines the direction of the most important current empirico-synoptical investigations of large-scale atmospheric processes. Of these we mention the work of Gordon /4/, in which an attempt was made to explain the weather anomalies in Great Britain in the summer of 1959 by the peculiarities in the transit of air masses over the whole northern hemisphere, depending on the planetary regularities of heat and energy balance. Wada Hideo /5/, proposed using the anomalies in the heat flux field for long-range forecasting, for example, the anomaly in the region of Taimyr in the winter of 1953/54, after which an extremely cold summer followed in Japan. Clapp /6/ plotted charts of the heat balance components of the lower 5-kilometer layer of the troposphere. The heating field was found to be similar to the temperature field (but phase shifted by almost 90°). The work of Palmen /7/ contains results of an estimate of the quantitative characteristics of the transformation of potential into kinetic energy over various regions of the northern hemisphere (it was established that the general rate of energy transformation in winter is of the order of 10 kw, so that the efficiency of the whole atmosphere is about 2%).

A number of works have already appeared mainly devoted to the mechanism of the formation of long-range weather anomalies — thermal interaction between the ocean and the atmosphere. Thus, in the work of Takenouchi and Hanazawa /8/, the relation between the temperature anomalies of the sea surface and the meteorological conditions over the north of the Pacific ocean is studied. In the work of Petterssen, Bradbury and Pedersen /9/ a review is given, and a theoretical model is proposed, of the relation of heat exchange and moisture exchange on the ocean surface with the development of extratropical cyclones. This was verified in the example of 10 situations over the North Atlantic. In the work of Pagava /10/ the relation between the thermal state of the North Atlantic and the air temperature in Europe was studied; it was established that in a number of cases in Europe the sea temperature, the heat exchange between the sea and the air, the circulation over the sea and the temperature, are closely related to one another. Bjerknes' paper /11/ gives a synoptical review of interaction processes between the ocean and the atmosphere in the North Atlantic. From data over many years, the relation between pressure variations in Iceland and on the Azores, and the variations in the sea temperature, is determined for a number of latitudes.

The investigation of the role of thermal effects in the formation of large-scale atmospheric processes has also been carried out theoretically. Thus, in the paper of De Lisle and Harper /12/ theoretical models are proposed for describing the influence of large-scale heat influxes on the zonal flow (the equations are solved for the conditions of the atmospheric circulation over Australia). Chao Ming-chi /13/ studies the stability of long waves subjected to nonadiabatic heating and to friction forces (in the quasi-geostrophic two-level model).

Of great interest for the understanding of the physical nature of large-scale atmospheric processes and of the general circulation of the atmosphere is the analysis of multiannual variations in circulation. Hupfer's paper /14/ is devoted to this problem. Data are here given to the effect that in 1901 -1930 features of zonal, and in 1931—1960 features of meridional circulation appeared over Europe. In the first of these periods the winter of the year was warmer, and the summer colder than the norm during 1761—1950. In the second period the summer seasons became warmer.

One of the major current methods of theoretical investigation of the nature of planetary atmospheric processes is the carrying out of numerical experiments on the general circulation of the atmosphere, i. e., the calculation of the meteorological fields for a long period on the basis of model equations proposed for describing planetary processes. Such numerical experiments open possibilities for the investigation of the most fundamental problems of long-range weather variations — the revealing of important initial data, the role of some nonadiabatic effects, and the significance of different coupling mechanisms between the atmosphere and the underlying surface. The first experiment of this kind, by Phillips (1957) made it possible, in particular, to explain the appearance of jet streams, the evolution of polar fronts and the tricellular structure of the general circulation. Szepesi's paper /15/ is devoted to a discussion of the results of this experiment and the prospects of further experiments of this type.

An important means of studying large-scale atmospheric processes is the statistical analysis of planetary meteorological fields. Of works of this field we mention: firstly, the paper of Chin Wan-cheng /16/, where the transient spectra of meridional momentum and heat currents in the period range from 2 to 60 days were calculated from the aerological data at the level from 700 to 50 mbar at two points in the USA. It was established, in particular, that in regard to momentum and heat currents long-period atmospheric disturbances (with periods over 20 days) are just as important as disturbances of shorter periods. In Barrett's work /17/ a harmonic analysis was made of AT-500 maps for the period 1—20 October 1950 and of AT-300 maps for January-February 1949, and the time variations in the amplitudes and phases of different harmonic components of these maps were studied. The spatial spectra of the meridional momentum current at the 300 mbar level and the kinetic energy at a number of latitudes were calculated. The dominant role of the first, third and sixth harmonics over the latitude circles was established.

In the paper of Gandin and Kuznetsova /18/ the results are given of large-scale structure functions of the 500 mbar geopotential and of the wind velocity vector at the 500 mbar level. It was noted in particular that the correlation between geopotential values at distances over 300 km becomes negative. In Yudin's work /19/ the correlation functions of the geopotential of the isobaric surfaces 850, 500 and 300 mbar, which were described by empirical formulas of the type $B(l) = B_0(1+al)e^{-al}$, were determined by means of improved computational schemes (taking into account not only the first, but also the second and third differences). By means of these functions the spectra of the geopotential and of the geostrophic wind were calculated.

An original method of statistical analysis of circulation variations over the Northern Hemisphere was used in the work of Chaplygina /20/; a study was made of the alternation in time during 1899—1954 of B. L. Dzerdzeevskii's "elementary circulation mechanisms," divided into 13 types. The probability of each type after each fixed previous one was calculated, and it was established that in the first approximation the alternation of circulation types can be represented by the scheme of a simple homogeneous Markov chain. This means, in particular, that the "elementary circulation mechanisms" possess only a very short after-effect, comparable with the mean duration of these "mechanisms" (amounting to only several days).

2. Synoptic Processes and Short-Range Weather Forecasting

Whereas in the field of long-range weather forecasting the scientific formulation of the problem (which should be directly based on the laws of physics, and not on some physically unexplainable empirical asynchronous relations between macroprocesses) is only now being placed on a scientific basis, the description and short-range forecasting of synoptical processes have been going on for more than ten years. As a result short-range forecasts of synoptical processes have already been brought to the stage of wide operational use. The indicated scientific basis was used for describing relatively slow synoptical processes (in contrast to rapid wavy processes) by means of the equations of hydrodynamics and thermodynamics in the quasistatic and quasigeostrophic (or quasisolenoidal) approximation. Since over short periods synoptical processes can be considered as adiabatic it is possible to use simplified equations of conservation of the potential vorticity and of the entropy for accurate forecasting. Current investigations on this problem are mainly directed at improving these equations, working out and testing numerical schemes to solve them, with a proper allowance for the vertical thermal structure of the baroclinic atmosphere. In 1962 a large number of works of this kind were reviewed in "Referativnyi Zhurnal "Geofizika," of which we mention only a few which in our opinion have some basic new elements.

The substantiation of the modern theory of short-range forecasting of synoptical processes was based on a detailed analysis of the behavior of wave disturbances in the atmosphere. The investigation of the behavior of different wave types is of interest not only for the theory of synoptical processes, but also for the theory of atmospheric influxes, for a number of problems of atmospheric acoustics and for other problems. The work of Dikii /21/ was devoted to a further development of the theory of wave disturbances in the atmosphere; the influence function of a point source of wave disturbances in a baroclinic isothermally stratified atmosphere was studied. Dikii succeeded in separating components corresponding to acoustics and gravitational waves, and in finding out their asymptotic form for large time values.

A number of works considered the role and methods of allowing for non-adiabatic factors in the description and forecasting of synoptical processes. Thus, the work of Spar, Gerrity and Cohen /22/ compares 12-power forecasts prepared by means of a barotropic and three-baroclinic models, and analyses the effect of the baroclinicity, the heat flux from the sea surface and of the latent condensation heat. Duquet's paper /23/ shows a multi-layer quasigeostrophic model of the atmosphere, taking into account heating from the underlying surface and release of latent condensation heat. The variations in the surface air temperature, calculated by means of this model in a number of examples, made it possible to determine the zones of frontogenesis at the Atlantic coast of the USA. Kibel' and Sadokov /24/ consider a model taking into account heat flow to the atmosphere from the underlying surface due to turbulent heat conductivity of the air, the condition being that at the surface of the earth there is a balance of old types of heat fluxes. They proposed to integrate the resulting equation for the variations in the geopotential simultaneously with the equation of heat transport in the soil. Sutton's paper /25/ gives information on the technique of numerical weather forecasting used in the Meteorological Administration of Great Britain. This technique is based mainly on the two-level quasigeostrophic model of Bushby and Sawyer, but it is mentioned that in a number of cases allowance for heat inflow to cold air masses from the ocean surface (and also the replacement of the quasi-geostrophic by the quasi-solenoid approximation) gave an appreciable effect.

Of works containing technical improvements in the computational schemes for numerical forecasting of synoptical processes, we mention the paper of Bushby and Whitelam /26/, in which an improved three-parameter quasigeostrophic model of the atmosphere is proposed. This makes it possible to forecast particularly the AT-1000, and this more accurately than by the two-level model of Bushby and Sawyer, and with accuracy comparable to synoptical forecasting. Of great methodical interest is the work of Lorenz /27/, in which a maximally simplified model of the dynamics of synoptical processes is considered—a barotropic equation for the vorticity, where the vorticity $\Delta\psi$ is in the form of a sum of three waves $A \cos ly$, $F \cos kx$ and $2G \sin ly \sin kx$, where A, F and G are required functions of the time. They can be found either analytically (expressed in terms of elliptic functions) or by numerical integration of the corresponding ordinary differential equations. This model makes it possible to calculate the evolution both of the zonal current (the quantity A) and of the disturbances (the quantities F and G) and to estimate the rate of energy exchange between them. It is thus possible to draw qualitative conclusions about the evolution of a number of synoptical patterns.

We also mention Knighting's paper /28/, devoted to a diagnostical calculation of the field of synoptical vertical motions. Firstly, the field of the vertical velocity at the middle level in the troposphere was calculated, the results being in good qualitative agreement with the synoptical data. Secondly, from data of aerological maps of the levels 1000, 900, . . . , 300, 200 mbar, the vertical velocity profiles at 480 points of a horizontal network were calculated. It was found that the obtained profiles conform well to the regions of the patterns on the synoptical map. The profiles at neighboring points inside a given region are, as a rule, close to one another and their form changes smoothly in passing from one region to another. In regions of considerable vertical velocity the profiles have a parabolic form with a maximum near the middle level in the troposphere.

Finally, Wexler's paper /29/ deserves attention. He writes on various improvements in the Washington Joint Center of Numerical Weather Forecasting. Along with automatization of the processing of the meteorological data and an objective analysis of the maps, he indicates the use of a quasi-solenoidal model for forecasting maps of the Northern hemisphere, methods of stabilization of super-long forced waves and the use of a baratropic model for forecasting the motion of hurricanes along the leading current. In addition, he describes numerical methods used in Washington for forecasting averaged five-day maps, and mentions numerical experiments of Smagorinskii on the general circulation and on the allowance of condensation processes.

An important aid in the preparation of numerical forecasts of synoptical processes, making it possible to achieve an appreciable improvement in the quality of such forecasts, is the use of statistical methods for objectively analyzing synoptical and aerological maps. Gandin's paper /30/ is devoted to this problem. It contains an account of some results of his investigations of objective analysis; also of methods of optimum interpolation of fields of meteorological elements (considered as individual realizations of random fields with given correlation functions) which make it possible to interpolate with the minimum root-mean-square error, the values of some field measured at nodal meteorological stations of a regular network (the field specifically considered is that of the geopotential of the 500 mbar surface). The interpolation accuracy can be raised by using for the analysis of the geopotential field data on the wind on the isobaric surface under consideration.

In Thompson's paper /31/ an original method of objective analysis and of forecasting synoptical processes in regions including poorly meteorologically explored territories is proposed (this method was tested by means of numerical experiments in the work of Richardson /32/). The method is based on the use of the barotropic equation for vorticity for forecasting for the middle level in the atmosphere. The vorticity at the initial moment on the unexplored territory is assumed to be constant (equal to the circulation on the boundary of the territory divided by its area), and in the following moments the observed vorticity on the unexplored territory is given in accordance with the calculated forecast. The stream function is then found from the vorticity and the boundary values by solving the Poisson equation. In this case the root-mean-square error of the geostrophic wind on the unexplored territory decreases exponentially with time.

It should be noted that in the field of weather forecasting (as well as of forecasting of any other phenomena both geophysical and other) along with the task of improving the forecasting technique (and, consequently, raising its quality) a not less important task is to provide for a rational use of the forecasts. It is obvious that without solving the second of these problems an improvement in the forecasting quality cannot raise their practical effectiveness. Moreover, economically useful results can also be obtained from forecasts of low reliability and even from climatological data alone if the data are analysed correctly. However, in most cases a rational use of forecasts by consumers is not yet organized. Monin's paper /33/ is devoted to methods of such rational use. It considers forecasts of phenomena which can be divided into a finite number of phases $\Phi_1, \Phi_2, \ldots \Phi_n$, and shows that for a complete estimation of the quality of the forecasts it is necessary to have a table of probabilities p_{ij} of the occurrence of the phases Φ_j in forecasts of Φ_i. For an optimum use of the forecasts by a given customer it is necessary also to have a table of his profits and losses s_{ij} in cases when he based himself on the realization of the phase Φ_i and the phase Φ_j actually occurred. It is shown in the paper how by means of tables of p_{ij} and s_{ij} an optimum strategy for the use of forecasts by a customer can be worked out, providing on the average the best estimate of the economic indices of his activity.

One must mention the important new method of meteorological observations of synoptical processes — the use of artificial meteorological earth satellites. This method creates possibilities for obtaining new types of meteorological information — in the first place cloudiness maps on the scale of the whole planet (including territories like the oceans, poorly explored by usual meteorological observations) as well as the outgoing radiation fields and, in the future, a number of other characteristics of interest for meteorology. The data of artificial meteorological satellites open wide possibilities for a radical improvement of the analysis of synoptical maps and for an improvement of short-range weather forecasting.

It may be assumed that in the future, it will be just the artificial earth satellites which will be able to give the information required for long-range weather forecasting. Of the works devoted to the use of such satellites worthy of mention is Hubert's paper /34/ which contains the results of an analysis of six photographs of the cloud field in the southern hemisphere, obtained from the satellite "Tiros I" on 28 April 1962. These photographs made it possible, in particular, to re-examine the analysis of the synoptical map in the South Atlantic and find in place of one cyclone, detected from the data of ship measurements, two cyclones with a clear system of fronts. Jones' paper /35/ gives data of the satellite "Tiros I," which recorded a cyclone three times, in May 1960, in the region of the Bermuda Islands, its life cycle having been followed during 86 hours from the phase of maximum development to fading. Ornum's paper /36/ describes a technique of the possible use of artificial satellites for determining the altitudes of layers of different densities and, in particular, for plotting altitude maps of the tropopause, which may be a valuable help in the analysis of synoptical processes.

3. Processes in the Stratosphere

The study of the structure of the stratosphere and of the dynamic processes taking place in it has become in recent years one of the most actively developed subjects of synoptic meteorology. Interest in it is due in the first place to the practical needs of modern aviation, which has largely passed to flights at altitudes of 10—12 km, thus utilizing higher layers of the atmosphere. From the theoretical viewpoint the stratosphere is of interest to many investigators as a medium through which variations in solar radiation may affect ground weather. However, the physical mechanisms of such an effect, even the possibility of its existence, remain as yet completely unclear, and the theory of stratospheric influence on the weather lacks any real proof. Besides, the finding of the features of the dynamical processes in the stratospheric layers, in which active absorption of short-wave solar radiation by ozone takes place, is of scientific interest even without reference to the weather in the troposphere.

As a result of the improvement and development of observation means of high-altitude aerology, including meteorological rockets, stratospheric processes became accessible in the post-war years in regular meteorological observations. It can be said that meteorology has entered the period of synoptic mastering of the stratosphere. A final dynamic theory of stratospheric processes has not yet been created, there being as yet insufficient empirical basis for this. Investigations of stratospheric processes are therefore carried out mainly by qualitative empirico-synoptic methods. Since in the investigation of synoptic processes in the troposphere quantitative theoretical methods of dynamic meteorology have acquired the dominant role, it can be said that stratospheric processes have become at present the main object of empirico-synoptic investigations.

An extensive investigation creating a solid empirical basis for a synoptic study of stratospheric processes was published in a series of papers /37/ by a group of German authors (Bickert, Bork, Hertel, Kovâc, Kriester, Labitzke-Behr, Petkovsêk, Petzoldt, Scherhag, Sieland, Stuhrmann, Warnecke). These papers give the daily AT-10 and AT-30 maps for 1960—1961 and for the first quarter of 1962, as well as AT-50 maps for 1960 and AT-100 maps for two quarters of 1962. A quarterly synoptic summary of the processes traced in these maps is also given.

The observation results show that the temperature, pressure and wind fields in the stratosphere possess a much sharper space and time variability than the fields in the troposphere (this is natural, since the stratosphere, containing a relatively small air mass, should react much more sharply to an energetic effect of fixed intensity than the troposphere, which contains a large mass of air). Thus, for example, in Sawyer's paper /38/, the results of pilot balloon measurements at altitudes of 10—20 km over England are reported, indicating quasi-periodical wind velocity and direction variations with altitude, approximately maintaining their character during several hours. The vertical scale of the corresponding atmospheric disturbances (having apparently ageostrophic character) is of the order of magnitude of a kilometer, the horizontal scale — of hundreds of kilometers. As a possible explanation of this phenomenon, slow inertial oscillations with a period of the order of 6 hours are indicated. The paper of Hopper and Laby /39/ describes data on the wind in the stratosphere, obtained in Australia and South Africa by means of meteorological air balloons with automatic valve, which ascend to altitudes of 24—36 km. It notes that the wind field is strongly dependent on the latitude and is weakly dependent on the longitude of the location. At an altitude of 30 km sudden wind variations are observed almost simultaneously at stations of the same latitude. It is proposed to explain these variations as due to effects of heat absorption in the ozone layer. Barbe's paper /40/ reported that at altitudes of 20—35 km in the region of Paris, where a western wind prevails in winter (winter stratospheric monsoon), sudden appearances of eastern winds, established for periods of several days and even several weeks, are sometimes observed. Barbe explained this phenomenon as due to effects of radiant energy absorption in the layer under consideration and the corresponding reversal of the meridional pressure gradient.

Panofsky's work /41/ formulates along with some data on the mean regime in the stratosphere (a table of the mean altitudes of the isobaric surfaces from 200 to 10 mbar is given); an empirical rule for the increase in the intensity of warm crests and cold troughs with altitude, and the decrease in intensity of cold crests and warm troughs. Distribution schemes of the zonal wind in winter and summer are analyzed. The phenomenon of "explosive warmings" in the polar stratosphere in winter, most pronounced above 20 km and sometimes reaching 50° during a period of about 10 days, is reported. A possible explanation is the existence of vertical motions with a velocity of up to 5 cm/sec. Labitzke's paper /42/ is devoted to the problem of sudden stratospheric warmings and their relation to processes in the troposphere. After a description of the technique of plotting AT-10 maps, Labitzke analyzes winter stratospheric warming associated with displacements of the Aleutian anticyclone, and sudden warmings, presumably arriving from the tropics. He notices that a stratospheric process is always observed for several days before the parallel tropospheric process. Spring stratospheric warmings are also analyzed, and the great variability of the spring stratospheric circulation from year to year is indicated (for example the difference between the AT-10 altitudes in March 1960 and 1961 reached 2 km).

Of the works devoted to ascertaining the mean regime of the stratosphere we give here the paper of Goldsmith and Brown /43/, in which a stratospheric circulation scheme, being an improvement on the scheme of Dobson-Brewer, is proposed. According to this scheme, the meridional air transport in the stratosphere from the equator to the pole has the highest velocity at the tropopause, where the air passes from the equator to moderate latitudes in not more than 2 months. In the ozone layer the air stays about a year. Above 25 km large-scale meridional and vertical motions are assumed missing, but there is small-scale meridional diffusion. The existence above 25 km of a considerably higher humidity than at an altitude of 15 km indicates a low intensity of vertical exchange. In /44/ Pogosyan determines and analyses the mean values over 1957—1959 of the temperature of January and July on the isobaric surfaces 500, 300, 200, 100, 50, 30 and 15 mbar and the temperature and wind velocity profiles up to an altitude of 90 km at a number of latitudes. He also discusses the causes of winter warming of the Arctic stratosphere and recognizes that these causes are heat advection from mid-latitudes and adiabatic effects of vertical motions.

In a number of works a model of a vertical structure of the stratospheric circulation was developed, based on the idea of the presence of "zero" layers, in which the vertical velocity vanishes and an ageostrophic mass transport takes place. At an altitude of 55 km, between the latitudes 30 and 9C° a zero layer of the first kind, N_1, is observed, with a super-gradient maximum of wind velocity and with a reversal of the horizontal temperature gradient. At an altitude of about 20 km a zero layer of the second kind, N_2, connected with a minimum wind velocity is found in winter, and in summer at the same altitude a zero layer of the third kind, N_3, in which a transition from lower western to upper eastern winds, is observed; see, e.g., the paper of Freitag and Faust /45/.

Attmannspacher's paper /46/ suggests that the layer 20—60 km forms a dynamical system independent of the lower-lying layer and controlled by the zero layer N_1, for which the heating surface is the upper boundary of the ozone layer. The seasonal variations in the stratospheric circulation are analyzed from this point of view. Faust's paper /47/ is devoted to the study of the dynamics of the stratospheric zero layer N_1 as compared with the tropospheric N_1 layer, situated on the average at the 10 km level. In particular the altitude variations $h(t)$ in the stratospheric layer N_1 as dependent on the mean temperature of the layer between 20 km and N_1 were studied and it was established that in winter $h \sim 50$ km, in summer $h > 60$ km and in spring and fall the curve $h(t)$ has discontinuities. The second paper by this author /48/ contains a qualitative explanation of the causes of the formation of zero layers and a discussion of the properties of the stratospheric dynamical system occupying the layer 20—90 km. In particular it considers the problem of the possibility of the formation in the upper stratosphere of high- and low-pressure regions, not connected genetically with the barometric formations in the lower dynamical system (0—20 km).

A detailed review of different models of the meridional circulation in the stratosphere and mesosphere is given in Wilckens' paper /49/. Considered there are:

Gold's model, consisting of three circulation cells over each hemisphere (troposphere, a layer from the tropopause to an altitude of 30 km and the higher-lying layer);

the model of Kellog and Shilling with a single stream in the layer of 20—55 km from the pole of the summer to the pole of the winter hemisphere, with a zone of variable winds in the layer of 60—80 km, and above it, with two circulation cells with an ascending branch over the equator and with descending branches over the poles;

the model of Libby and Palmer with a circulation "wheel" in the layer 17—25 km.

the model of Murgatroyd and Singleton with transport to the summer pole below 30 km, with a weak transport to the winter pole in the layer 30—50 km, and with a strong transport in the same direction above 50 km (with a maximum at an altitude of 75 km and at the latitude 40°).

the model of Gaurvitz with two circulation cells involving layers 25—30 km thick each and coming into contact at an altitude of about 60 km.

the model of Faust and Attmannspacher with a zero layer N_1 at the level of the stratospause (55 km).

It is noted that the data on the temperature in the stratosphere and mesosphere are in favor of the conclusions of Murgatroyd.

We mention finally the works of Angell and Korshover /50/ and of Reed /51/, which report the observation of oscillations in the zonal component of the wind velocity and of the temperature in the tropical stratosphere with a period of about 26 months. According to the former /50/, such oscillations are observed in the zone from latitude 30° north to latitude 30° south on the isobaric surfaces 50, 25 and, possibly, 10 mbar. With decreasing altitude they weaken and at the 100 mbar level they are no longer distinguishable; the possibility of observing such observations at moderate and even at polar latitudes is discussed. According to /51/, these oscillations are observed in the layer 15—30 km and weaken when approaching the tropopause. In this case the temperature oscillations have an amplitude of 2—3° and are phase shifted with respect to the oscillations of the zonal wind.

4. Special Meteorological Phenomena and Special Meteorological Regions

Along with the investigation of the general dynamics of atmospheric processes, of great theoretical and practical interest is the detailed study of individual meteorological phenomena — jet streams, typhoons, tornadoes, drifting snows, dust storms, thunderstorms, etc., which often lead to natural calamities, causing material damage to people. The study of such phenomena may aid in improving methods for their prediction, as well as in developing measures for the prevention of damage they may cause. In addition, the setting up of theoretical models of these phenomena in combination with synoptical data may help in the solution of a number of problems of the physics of atmospheric processes.

In 1962 in "Referativnyi Zhurnal Geofizika" a large number of works were reviewed devoted to a synoptical description of typhoons and to attempts at a physical explanation and forecasting of their behavior. However, in our opinion, any decisive results that could be the basis for forecasting the formation and evolution of typhoons have not yet been obtained. We will therefore not consider here the results of individual works. We will also not analyze works devoted to the investigation of such, no longer new, phenomena as tropospheric jet streams, and will mention only the paper of Newton and Perrson /52/, in which a detailed description is given of the structure of a meridional vertical cross section of the troposphere in the vicinity of a subtropical jet stream, based on an analysis of several jet stream cases.

The papers of Barad /53/ and Wexler /54/ report the observation of a new and interesting meteorological phenomenon — jet streams at low levels. According to /53/ in the layer from 250 to 600 m wind velocities up to 22 — 35 m/sec are often observed, sharply decreasing above this layer to values of 5 — 10 m/sec. These air streams sometimes have a length of up to 1600 km and a width of 90 — 800 km. It is assumed that the cause of the formation of such jet streams is the diurnal variation of the temperature of the earth's surface and, consequently, of the turbulence in the lower air layers. Similar jet streams in the lower 2-kilometer layer of the atmosphere are reported in /54/ and indication is given of a diurnal variation in these streams with such a strong night maximum that the stream becomes super geostrophic.

Dyunin /55/ gives an account of the principles of the theory of drifting snows, for which use is made of the equations of the theory of two-phase flows (air plus snow particles), derived by hydromechanisms for the description of the motion of river sediments. The extensive work of Romanov /56/ is devoted to a statistical-synoptical investigation of dust storms, their frequency in various regions of Central Asia, the annual and diurnal variation, classification, visibility range, aerosynoptical conditions of their formation, and finally recommendations for their prediction.

Vul'fson's book /57/ gives an account of a number of results of an investigation of convective motions in the free atmosphere, including clouds, by means of airplane measurements of the air temperature by sensitive thermometer. Vul'fson found that convective motions in the free atmosphere have the form of individual ascending jets of warm air in a relatively cold surrounding medium, and gives data on the quantitative statistical characteristics of these ascending jets in different meteorological conditions. Webb's paper /58/, containing a development of Priestley's dynamical convection theory, is devoted to a theoretical description of thermal convection. From an analysis of the equations of this theory the conclusion is drawn that in the layer $0.03\ L < z < L$ (where L is the so-called scale of the dynamical air sublayer, proportional to the cube of the friction velocity and inversely proportional to the vertical turbulence heat flux) the temperature gradient is approximately proportional to $z^{-4/3}$ (free convection law), but in a forced convection layer $z < 0.03\ L$ and, what is unexpected, above the level this law is not observed. It should be noted however, that the equations of this theory have largely a model character. The work of Priestley /59/

deals with another aspect of atmospheric convection, i.e., the study of large-scale convective cells. From cloud photographs obtained by means of artificial satellites it was established that the ratio of the width to the height of convective cells is equal to 30, whereas in small-scale cells this ratio is equal to three. Priestley proposed to explain this change in the geometry of convective cells by the anisotropy of small-scale turbulence, owing to which the horizontal mixing coefficients are considerably larger than the vertical mixing coefficient.

Owing to a number of specific features of the meteorological processes of the equatorial zone and of the polar regions, these regions of the terrestrial globe can be recognized as special meteorological regions. The degree to which they have been studied differs very much. Arctic meteorology is tens of years old and the basic features of the meteorological processes in the Arctic are known in almost as much detail as the processes at moderate latitudes. Investigations in Arctic meteorology during the last ten years have been generalized, for example, in Belmont's paper /60/. Antarctic meteorology actually appeared only after the International Geophysical Year of 1957 – 1958, although during the past few years a number of books and many papers on the peculiarities of the meteorological processes in Antarctica have been published. The meteorological study of this region is of course still far from complete. Of the review works on the synoptical meteorology of Antarctica we indicate Khromov's paper /61/, which considers problems of stability and structure of Antarctic anticyclones; cyclonic activity at the coasts of Antarctica; polar fronts in Antarctica and their role in cyclogenesis; the regeneration of cyclones on Antarctic fronts and the formation of central cyclones at the coasts; the role of the relief in cyclogenesis; fronts between the sea and the continental Antarctic air; the meridional and zonal circulation in the Southern Hemisphere and katabatic winds in Antarctica.

As concerns the equatorial zone, its meteorological study has just begun. Owing to the small number of regularly operating meteorological stations in this zone, it is still very poorly explored by meteorological observations. At the same time, the theoretical approach encounters a number of specific difficulties which cannot still in any way be considered overcome — the vanishing of the vertical component of the Coriolis force and as a result the absence of a geostrophic wind; the presumably great dynamical role of the condensation heat of water vapors over the oceans.

5. Atmospheric Turbulence

A thorough study of atmospheric turbulence is one of the important problems of theoretical and experimental meteorology. In fact, turbulence determines the dissipation mechanism of the kinetic energy of atmospheric motions. It is also responsible for one of the main roles in processes of heat and moisture transport inside the atmosphere, and in processes of thermal and dynamical interaction and moisture exchange between the atmosphere and the underlying surface, and thereby, in the transformation of air masses and long-range weather variations. Turbulence determines the structure of the planetary boundary layer of the atmosphere, the diffusion of atmospheric admixtures, the generation of wind-driven waves on the sea surface and air bumpiness, and it causes vibrations in ground installations.

Turbulent inhomogeneities in the refraction index lead to fluctuations in the amplitude and phase of light waves and radiowaves propagating in the atmosphere from surface and cosmic sources. The scattering of short radiowaves on turbulent inhomogeneities creates conditions for long-range radio and television communication. Besides its important role in many meteorological processes and phenomena, atmospheric turbulence is a convenient object for investigating a number of general mechanical regularities of turbulent flows of liquids and gases, having numerous applications in various fields of science and engineering.

In the current theory of turbulent flows different methods have to be used for describing the two main parts of the spectrum of the scales of turbulent inhomogeneities—the energy interval (i.e., the scale ranges comparable with the geometrical dimensions of the flow, which contains the main portion of the turbulent energy) and the equilibrium interval (i.e., the ranges of scales which are very small compared with the geometrical dimensions of the flow, in which the inertia forces and the viscosity forces acting on turbulent formations are in statistical equilibrium).

The description of small-scale turbulence structure (equilibrium interval) is based on the use of the theory of similitude for local-isotropic turbulence, developed by A. N. Kolmogorov and A. M. Obukhov over 20 years ago and serving as the basis for the entire subsequent development of the turbulence theory and its numerous applications, including those on meteorological problems. This similitude theory is based on the fact that the statistical regime of small-scale turbulence components is determined by only two parameters—the mean rate of turbulent energy dissipation ϵ and the fluid viscosity — and has a universal form (i. e. it does not depend on the large-scale features of the turbulence flow).

A new important step in the cognition of the laws of turbulent flow was the more accurate definition of the similitude theory for the equilibrium interval, proposed by Kolmogorov and Obukhov in 1961. The idea was described, in particular, in Obukhov's paper /62/. This improvement is due to the necessity to take into account not only the mean value of the dissipation rate of turbulent energy, but also the statistical fluctuations of the quantity, which in the case of a strongly developed turbulence with a large Reynolds number and a wide spectrum of turbulent inhomogeneity scales (as, in particular, atmospheric turbulence) are very intensive (and are already dependent on the large-scale features of the turbulence flow). Under some natural assumptions concerning the statistical law of the fluctuations in the quantity ϵ, it was established in /62/, for example, that the mean square difference in the rates at distances r from the inertial interval of the scale spectrum (the large scale part of the equilibrium interval, in which the influence of the fluid viscosity is negligible) is no longer proportional to $r^{2/3}$, as followed from the basic similitude theory, but to $r^{2/3}[1+M^2(r)]^{-1/9}$, where $M(r)$ is the coefficient of variability of the quantity E, averaged over a spherical volume of radius r. It can be taken that $M(r) \sim (L/r)^{4/3}$, where L is the external turbulence scale.

Another generalization of the similitude theory for the turbulence components of the equilibrium interval, developed by Obukhov, is connected with allowance for temperature nonuniformities of the turbulent medium, which leads to the appearance of additional determining parameters—the mean dissipation rate N of the temperature nonuniformities and the fluid thermal conductivity, and in the case of stratified medium in a gravitational field — also the buoyancy parameter g/T_0 characterizing the Archimedian accelerations (g — the gravity acceleration, T_0 — the mean temperature). Monin's paper /63/ gives a calculation of the form of the spectra of the kinetic energy, temperature nonuniformities and turbulent heat flux in the inertial interval (in which there are only three determining parameters ϵ, N and g/T_0) for the case of atmospheric turbulence, for which semi-empirical equations are used for the spectra, similar to Eizenberg's well-known equation. As a result it is found that the Archimedian forces lead to a regular deviation of the spectra in the range of small wave numbers k in the inertial interval from the proportionality law $k^{-5/3}$, which is valid in the absence of Archimedian forces.

Large-scale turbulence components whose scales belong to the energy interval of the spectrum play a great role in many hydrodynamical processes (for example, in the process of turbulent diffusion). The theoretical description of these components is mainly based on the ideas of the so-called semiempirical theory of turbulence, which in the case of an incompressible fluid is conducive to the well-known logarithmic law for the velocity profile in the boundary layer about a plane plate around which the fluid streams. When applied to the turbulence in the surface air layer, the theory of the logarithmic boundary layer required extensions owing to the necessity to take into account the influence on the turbulence of the thermal stratification of the air and of the Archimedian forces arising in this case. Such an extension, proposed over ten years ago by Soviet authors, was formulated in the form of a similitude theory for turbulence in the surface air layer based on the allowance for three determining parameters — the vertical turbulent momentum and heat flows and the buoyancy parameter g/T_0. This theory was first used for describing averaged profiles of the wind velocity, temperature and passive admixtures in the surface air layer. In Taylor's paper /64/ this theory is used to analyze data of careful profile measurements, which confirmed the main conclusions of the similitude theory. Subsequently this theory came to be used for describing not only average profiles, but also statistical characteristics of the fluctuations in the wind velocity and temperatures in the surface air layer.

In recent years new data on measurements of the characteristics of atmospheric turbulence have been obtained. Thus, Davenport's paper /65/ gives data of measurement and analysis of spectra of horizontal gustiness components during strong winds. It is observed that a minimum of the spectrum occurs in the vicinity of wave-lengths of the order of 10 km, a maximum at wavelengths of about 1 km; and for wavelengths smaller than the observation altitude the form of the spectrum agrees with the theoretical predictions for the inertial interval. In the work of Panofsky and McCormik /66/ data of measurements of the spectra of vertical wind velocity fluctuations in the surface air layer, obtained by many authors, are generalized and they describe the spectra by a formula of the type $nS_w(n) = \overline{w^2}F(nz/V)$, where n is the frequency, z — the altitude, V — the wind velocity, w — the vertical velocity component. For the form of the function F and the dependence $\overline{w^2}$ on the meteorological conditions, empirical formulas are proposed. Smith's paper /67/ deals with the same problem. Here data of measurements of the spectra $nS_w(n)$ by means of captive balloons at altitudes of 160 — 1600 are given. It was noticed that the spectra have a maximum for a wavelength of the wind field inhomogeneities of about 300 m, only slightly varying with altitude. In the work of Ivanov and Klinov /68/ some results are described of measurements of the characteristics of atmospheric turbulence (its intensity, scales, exchange coefficients) on the unique 300-meter meteorological tower of the Institute of Applied Geophysics.

Dyer's paper /69/ describes the organization and some results of pulsation measurements of vertical turbulent heat and moisture flows in the surface air layer by means of automatic instruments developed by the Department of Meteorological Physics in Aspendale (Australia). Pulsation measurements of the vertical moisture flow, constituting for the time being the only example of measurements of this kind, were made by means of dry and wet-bulb resistance thermometers, an electric model for determining the saturation parameters, a thermo-anemometer and an automatic correlator. In contrast to some authors, who vainly strived to close the equation of heat balance of the earth's surface in each individual measurement, the closure here is verified statistically from large sets of individual measurements. It was found that the equation closed well on the average, but the spreads of the individual results was fairly large. In Gurvich's paper /70/ unique measurements of the spectrum of the vertical turbulent momentum flow (in the frequency band of 0.002 — 50 c. p. s.) are reported. According to the first examples obtained of such spectra, the main contribution to the momentum flow at an altitude of 1m in the case of unstable stratification was made by turbulent vortexes with scales ranging from several meters to tens of meters.

Of the works in which new principles for measuring turbulent characteristics are proposed, we mention the paper of Franzen, Fuchs and Schmitz /71/, which is devoted to the corona anemometer, based on the wind effect on positive ions in the corona discharge. Here the preparation of the instrument model is given with examples of the measurement of turbulence spectra behind the grill, in a wind tunnel in the frequency range from 30 to 8000 c. p. s. In the works of Gorelik and Mel'nichuk /72/ and of Stackpole /73/ a method is described for estimating the turbulence spectra in volumes containing cloud particles or precipitation from the fluctuations of a radar signal. In /72/ a number of formulas for such estimates are given, and in /73/ some measurement results are also reported. It is observed, for example, that the turbulence intensity at different altitudes (from 200 to 6000 m) varies periodically with a frequency of 0.005 c. p. s. and that in rains there are alternating zones of intensified and attenuated turbulence with distances between them of about 3.5 km (i. e., of the order of the dimensions of convective cells). We mention, finally, Taylor's paper /74/, in which for ship measurements of turbulent momentum and heat flows the author recommends the use of formulas relating these quantities to the gradients of the wind velocity, temperature and the parameters ϵ and N. These can be determined from data of measurements of the structure functions of the wind velocity and the temperature in the inertial interval of the scale spectrum (the measurement of structure functions is not disturbed by the ship's pitching).

Turbulence data find application in the first place for describing the meteorological regime in the planetary boundary layer of the atmosphere. The problem of simultaneous determination of the structure of this layer and of the turbulence characteristics is dealt with by Laikhtman's investigation /75/ and also in the work of Kazanskii and Monin /76/. In the latter, for the case of a neutral thermal stratification, the relation is established between the turbulent friction stress at the earth's surface and the "external parameters''—the geostrophic wind velocity G, the Coriolis parameter l, and the roughness z_0, having the general form $/G=f(G/z_0l)$, where v_* is the friction velocity. In the paper of Blackadar, Panofsky et al. /77/ a number of new observation data on the wind profile and on the turbulence characteristics in the planetary boundary layer of the atmosphere are given and compared with the theoretical predictions. In particular it is observed that the region of applicability of the logarithmic law for the wind profile is small. The spectrum of the horizontal component of the wind velocity is subdivided into two intervals corresponding to mechanical turbulence (with short wavelengths—up to 100 m) and to convective turbulence (with wavelengths from 200 m to several kilometers).

In conclusion we consider works devoted to atmospheric diffusion. We will not analyze in this connection the numerous works in which, from data on diffusion at small distances from the sources (hundreds of meters and kilometers), an estimate is made of the parameters of the well-known formulas of Sutton, Laikhtman and others, or in which some empirical formulas are proposed. We will mention only two works having the character of novelty. The work of Smith and Hay /78/ describes an improved theory of the scattering process of a cloud of particles (with a gaussian distribution of particle concentration in space) in the field of a stationary, homogeneous and isotropic turbulence, with generalization to the case of heavy particles with a fixed rate of gravitational deposit. The obtained formulas are the result of experiments on the diffusion of spores of lycopodium powder and fluorescent particles thrown from an airplane. Pasquill's paper /79/ considers the least studied problem of atmospheric diffusion — the scattering of impurities at distances ten and hundreds of kilometers from the source. Some results are there given of experiments with diffusion of fluorescent particles at distances of 15—150 km, carried out by the British meteorological service jointly with the Chemical Defence Experimental Establishment, Porton Down. It is observed that the velocity of an impurity cloud is usually close to the mean wind velocity in the mixing layer, and that an effective mechanism of horizontal mixing is the joint action of the vertical gradient of the wind velocity and of the vertical mixing.

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Professor S. P. Kromov

CLIMATOLOGY

1. Complex Climatic Descriptions

The present review mentions only works dealt with in the "Referativnyi Zhurnal Geofizika" for 1962. A considerable part of these works was published in 1961, the remainder in 1962 and only isolated papers earlier than 1961.

Climatological literature till now has consisted mainly of climatic descriptions or analyses of the regime of individual climate elements for different places on the terrestrial globe. To some extent such works are a popularization of already known climatic facts or their interpretation from a definite viewpoint, for example, agricultural or medical. But many of these works also contain new results obtained by a detailed climatic study of regions previously insufficiently explored (e.g. health resorts, large towns and regions of new agricultural development), as well as when determining the genetic regularities of the climate in specific geographical examples.

Of the most significant complex climatic descriptions of 1962 the following should be mentioned: the investigations of the climate of the Sahara from 168 stations (Dubief /1/); Arizona from 110 stations (Sellers /2/); Ethiopia (Hovermann /3/); the Antarctic continent (Rusin /4/); the ice sheet of Greenland (Gerdel /5/); the llanos of Venezuela (Carrillo /6/); Rumania (Stoenescu /7/); the Bulgarian coast of the Black Sea and of the Bulgarian health resorts (Kirov /8/); a number of administrative regions, territories, and republics of the USSR, such as East Siberia (Shcherbakova /9/ in the next number of the series "The Climate of the USSR", issued by GGO); Turkmenia (Myagkov /10/); Abkhazia (Kordzakhia and Dzhavakhishviki /11/); Buryat republic (Zhukov /12/); Titinskaya distric (Zhukov /13/); Kaliningrad district (Fedorov et al. /14/; by the method of complex climatology); the Carpathian regions of the Ukraine (Andrianov /15/); Karakumy (Semenova /16/); the health resorts Borzhomi-Bakuriani (Kordzakhiya et al. /17/); Yany-Kurgan (Klyuchnikov /18/) and others.

2. Precipitation Regime

An even larger number of works were devoted to indivual climatic elements. To describe them fully here is not possible, but as an example we confine ourselves to an incomplete listing of works concerned with only one climatic element, namely precipitation.

The precipitation regime was investigated in various aspects and in various connections in Latvia (the influence of the relief and continentality, Grishin /19/); in Lithuania and in the Kaliningrad district (Buz /20/); in Belorussia (intra-annual distribution and confidence limits; Shebeko /21/), in the western regions of the Ukraine (moistening on the basis of N. N. Ivanov's coefficient; Kuznetsov /22/); in the Black Sea region (relation between moisture content and precipitation, Smekalova /23/); in Crimea (aerosynoptic conditions of considerable precipitation, Pol'skii, /24/); in the Urals (from 257 stations during 45 years, relation to altitude and orography, Shklyaev /25/); in East Georgia (abundant precipitation in relation to aerosynoptical genesis from 53 station during 25 years, Papinashvili /26/); in Armenia (on the lee slopes of mountains, an explanation is given of the fact that the precipitation is stronger on the lee than on the windward slopes /27/); in the Balkhash Basin (anual distribution /28/) ; on Sevan /29/; in the Austrian Alps (during 50 years from 99 stations /30/); in the Karinthian Alps /31/; in Bavaria /32/; in Italy /33/; in Slovakia /34/; in East Siberia (clarification of the influence of mountains /35/); in Bulgaria (synoptical genesis /36/); in Rumania (distribution of days with precipitation and synoptical genesis /37/); in Japan (dynamical climatology of precipitation, /38/); in India and Burma (monsoonal precipitation over 5-day periods /39/); in Pakistan /40/; in North America (dry and humid seasons /41/); in London (humid periods during 25 years /42/); in Africa (distribution over the months in percentages of the mean annual amount as related to seasonal displacements of the intra-tropical convergence zone /43/).

This far from complete list shows the range of geographical investigation on one climate element alone. In general, a similar picture exists for the air temperature, wind and other climatic elements. All investigations of this kind are modest bricks in the structure of the climatography of the terrestrial globe, but it is perfectly obvious that the climates of the earth have not been sufficiently studied, and that climatologists should not consider this work —the accumulation and explanation of facts pertaining to regional climatic conditions of the earth—as completed.

3. Data summaries

Primary data summaries in the form of atlases of maps and of diagrams and tables of climatic norms also continue to appear. In 1962 reference works appeared containing climatic norms for Rumania (1896—1955 /44/) and for the German Democratic Republic (1901—1950 /45/), a climatic atlas of North Rhine-Westphalia (77 maps to a scale of 1:1,000,000, Knoch /46/); in 1959, climatic maps for China also appeared , prepared from 249 stations /47/.

Along with these regional publications there appeared two data summaries of the widest range: the first issue of the World Atlas of Climatic Diagrams (Walter and Zieth /48/) with data on Africa, India and the Iberian Peninsula (this unique addition should cover 10 thousand stations during a period of 30 years); and the second volume of the World Climatic Data, covering Latin America and the Caribbean Sea from 2100 stations (Wernstedt /49/).

4. Classification of Climates and Climatic Regioning

A number of works dealing with problems of the classification of climates appeared in "Referativnyi Zhurnal Geofizika" in 1962. Garnier /50/ proposed a system of climatic criteria for the humid tropics. Dingens and Vernemmen /51/ determined climate types according to the Thornthwaite classification for 339 stations on the terrestrial globe, and plotted for them maps of the climatic factors according to Thornthwaite, i. e., total evaporability, annual deficit and excess of moisture, moistening index and thermal effectiveness.

Koloskov /52/ described his experience in climatic zoning of the terrestrial globe in the interests of the agriculture of the USSR. The principles of this zoning were earlier given by the author. Sapozhnikova /53/ wrote about methods of agroclimatic zoning. G. J. Lopez and G. A. Lopez /54/ defined more accurately the distribution of climates of Spain according to Keppen's classification. Schmuck /55/ divided the territory of Poland into 36 zones according to the thermal regime. Maunder /56/ worked out a classification of the climates of the earth according to their influence on man. Babushkin /57/ proposed the principles of agroclimatic zoning for Central Asia and South Kazakhstan Andrianov /58/ for the Carpathian regions of the Ukraine. Avděičev /59/ carried out an agroclimatic zoning of Czechoslovakia according to the sums of active temperatures. Wissmann's work /60/ on vertical and horizontal climatic zones of high-mountainous Asia is connected with the vertical zonality of the climate. Davitaya and Mel'nik /61/ investigated the connection between climatic factors and the forest boundary.

Noteworthy is the work of Grigor'ev and Budyko /62/ on the climatic factors of geographical zonality, where indices of geobotanical and soil zonality are compared with the distribution of the radiational balance and of the radiational dryness index; a periodical system of climates is proposed.

We also note the new principle of genetic classification of climates, proposed by Gal'tsov /63/. He introduced as a climatic index the so-called vergency index, i. e., the difference between the pressure at the given point and the nearest point of the zero isoline between zones of prevalence of ascending and descending currents, and plotted a world map of this index for January. As another index the mean value of the surface vapor pressure was taken. Both these indices (in the author's opinion) reflect the atmospheric circulation, the radiation influx and the degree of moistening. An empirical formula for the dependence of the climatologic precipitation amounts on these indices is given, and maps of the precipitation regime over the terrestrial globe as dependent on their influence are plotted.

5. Radiation and Heat Balance of the Terrestrial Surface

In previous years the radiation-heat balance of the underlying surface was considered the most important factor of climate formation together with the general circulation of the atmosphere, and became a new important object of climatologic investigation. Known in this respect are the works of Budyko and his collaborators. In 1962 a new work of Budyko et al. /64/ on the heat balance of the surface of the terrestrial globe appeared. It reports that 79 world maps of the components of the heat balance for the whole terrestrial globe were plotted, taking into account the data of the International Geophysical Year, and will be published in a new edition of the "Heat Balance Atlas". A number of investigations of this group on the distribution of individual components of the heat balance were published almost simultaneously; but they were reviewed in the "Referativnyi Zhurnal Geofizika" in 1963 and therefore we will not consider them here.

A large monograph of Berlyand /65/ on the distribution of solar radiation on the continents was also published giving new maps of the accumulated radiation from direct observation data, and clarifying in detail the regime of accumulated radiation for individual continents. Barashkova et al. gave an analysis of the radiational regime of the territory of the USSR from direct observations at 98 surface stations, as well as from aerial albedo determinations. Data are given on the monthly and annual amounts of direct, diffuse and accumulated radiation, on their distribution over the territory, on their diurnal and annual variation; the same — for the effective radiation and the radiation balance. Larsson and Orvig published an atlas of the monthly-mean albedo values of the underlying surface of the Arctic /66/.

Notable is the very large number of investigations of the heat balance or of the regime of its individual components in the climatological aspect, but in a more particular geographic scale. Many such works have been carried out mainly by Soviet meteorologists.

There are such investigations also for the Arctic (Marshunova /67/) radiation balance of the underlying surface and of the atmosphere; Smetannikova /68/ — calculation of a number of components of the heat balance of the snow-ice cover; /69/ — radiation and heat balance of the Arctic; for the Barents Sea (Seryakov /70/ — the diurnal variation in the components of the heat balance); for the Norwegian Sea (Girdyuk /71/ — radiation balance from observations on the expedition vessel "Sevastopol" in 1957 — 1958); for Noril'sk (Rikhter /72/ — direct, reflected, accumulated and ultraviolet radiation); for the Novo-sibirsk islands (Ovchinnikov /73/); for the Krasnoyarsk region (Popov /74/); for Yakutia (Gavrilova /75/); for the central Chernozem regions (Kostin /76/ — calculation of the radiation and heat balance during 20 years); for the Saratov region (Beletskii /77/ — annual variation in the components of the heat balance during 20 years); for Evpatoria (Poltaraus /78/ — radiation regime in summer); for Karadag (Barashkova /79/ — radiation balance); for Armenia (Azatyan /80/ — radiational regime); for Turkmenia (Myagkov /81 — 85/ — monthly and annual radiational balance amounts for 13 points); for east Pamir (Veremeichikova /86/ — heat balance in summer in the Koshagyl valley; Kazanskii and Kolesnikova /87/ — radiation-heat balance of the Sel'dara River valley near the Fedchenko glacier) and others. In Rusin's monograph /88/ a detailed account is given of the radiation regime of Antarctica. Rusin also published a number of papers on radiation and heat balance and on heat exchange in the surface air layer in Antarctica /89 — 92/.

Abroad, investigations of the radiation and heat balance of the underlying surface were made for the British Isles at several points (Monteith /93/); for the North Atlantic (Shellard /94/ — calculation of components of the heat balance over months during 1948 — 1956 for two oceanic stations); for Hungary (Bacsó /95/ — components of the heat balance for each month). Rubin /96/ studied the heat balance of the Antarctic surface as connected with the ice balance and advection.

Budyko's work on the thermal zonality of the earth /97/ gives calculations of the annual variation in the water and air temperature in the absence of the ice cover of the Arctic seas. The summer water temperatures in the Arctic would be 5 — 10°, and the winter temperatures not below zero; the air temperatures in summer 10 — 20°, in winter 5 — 10°, so that once having disappeared the cover could not be renewed.

6. Heat Balance of the Atmosphere

Relatively few works are concerned with the heat balance of the atmosphere. The most extensive calculations were made by Davis /98/ who calculated the heat balance of the atmosphere from latitude 20 to 70° north and up to an altitude of 25 mbar over a number of seasons, by using aeroclimatic data. Hufnagl /99/ calculated the radiation balance of the free atmosphere over Vienna from temperature and humidity (radiosounding during 1953—1957) by means of El'zasser's diagram. In an already mentioned work /67/, Marshunova calculated the long-wave radiation and the outgoing radiation in the free atmosphere from aerological soundings at 15 stations in the Arctic.

7. Atmospheric Pressure

The second factor of climate formation is the general circulation of the atmosphere, directly determined by the pressure field.

Stakhnovskii's monograph /100/ appeared during the period under consideration. This was the most significant work for a number of years on the distribution of the atmospheric pressure at sea level over the terrestrial globe. It gave new monthly pressure distribution maps on a planetary scale, surpassing in detail all earlier ones. Schove /101/ plotted maps of 5-year and 30-year pressure anomalies for the terrestrial globe during the period 1875—1960.

Wege /102/ studied variations in the atmospheric pressure regime in the Northern Hemisphere from the period 1901—1930 to the period 1931—1960. He arrived at the conclusion that the continentality of the climate was increasing. The pressure gradient between the Azores and Iceland decreased from the first to the second period by 7 mbar.

On the basis of synoptical maps of the U.S. Weather Bureau for 7 years Berger /103/ plotted maps of the interdiurnal variability in the surface pressure over North America, North Atlantic and Europe for January and July, thereby correcting the conclusions of previous investigators beginning from Voeikov and Fikker. The diurnal, monthly and annual variability in the atmospheric pressure was investigated for the Netherlands and Budapest (Meijer /104/; Szalmáné /105/). Turusbekov /106/ investigated the diurnal variation in the atmospheric pressure at different levels (from 756 to 3610 m) in Kirgiziya.

Zastavenko's work /107/ studied the peculiarities of the pressure field in January and July over the Northern Hemisphere at altitudes up to 100 mbar (320 points during 1950—1956). Yaegasi /108/ studied the seasonal variation in the AT-500 geopotential in the Northern Hemisphere from maps of the U.S. Weather Bureau.

8. Wind Regime

A number of works dealt with the climatologic wind regime. Milevskii /109/ investigated its peculiarities in the Northern belt of the European part of the USSR from data of 12 stations and confirmed the idea of the monsoon character of the circulation in this region.

Morozova et al. /110/ studied the wind field over the mountain systems of Middle and Central Asia from monthly-mean profiles. The wind regime in the Apsheron Sea region was investigated by Kerimov and Koshinskii /111/; and in the region of the Novosibirsk and Krasnoyarsk water reservoirs, by Anapol'skaya and Budilova /112/. The wind regime in Bulgaria was studied by Barov /113/ from data of surface, aerologic and mountain stations in an atmospheric layer of 3.5 km during periods from 5 to 25 years, ending in 1945. The mean air transport in Potsdam during 1894—1956 was investigated by Boer /114/. Krishnan et al. /115/ studied wind variability high up over India.

Kuhlbrodt continued /116/ the processing of observations of the pre-war German expedition on the "Meteor" and published a work on high-altitude winds in the tropics of the Atlantic and the South Atlantic. Trenkle /117/ studied the zonal component of the geostrophic wind in the Atlantic-European sector of the Northern Hemisphere over months and 5-day periods at the 500 mbar surface at 55° north latitude.

Information of the wind regime in Antarctica is contained in the above-mentioned monograph of Rusin /88/. In addition to it we mention the work of Gus'kov /118/, who calculated from data of the International Geophysical Year the meridional wind components at various levels over months and over a year, and confirmed the existence of a stable anticyclone over East Antarctica. Rubin /119/ calculated mass advection through the boundary of Antarctica along the meridian for the surfaces from 850 to 100 mbar.

Harris et al. /120/ studied diurnal wind variation in the stratosphere and in the troposphere over the Azores from data for 3 years; Tarakanov /121/ did the same over the Rybinsk water reservoir, Ladoga Lake and the Baikal Sea from May to October.

9. Local Winds

We indicate separately some of the works on local winds. Vorontsov /122/ and Chestnaya /123/ studied local winds in Sevan; Péczely /124/ in Balaton; Monin /125/ in Grenoble; Dethorey /126/ mistrals in Montelimar for 8 years. Gianoli /127/ published a work on local winds over the whole Mediterranean Sea with a map of the prevailing directions.

Romushkevich /128/ dealt with sukhoveis in the steppe zone of the Ukraine at 30 stations during 1946—1954 and plotted in this connection the streamlines on the AT-850 and AT-700 mbar maps.

Gel'mgol'ts /129/ studied the mountain-valley circulation in the foothill zone of the Kirgiz range and of Trans-Ili Ala-Tau in a belt of about 600 km (on the northern slopes) from 33 stations during 5 years.

Mountain-valley winds on the slopes of Fujiyama were studied by Fudzimuro /130/.

Rajan /131/ made a statistical investigation of squalls in Bangalur during 1937—1958 from data of self-recorders. Breezes on the coasts of the Soviet Arctic were studied by Shapaev /132/.

10. Wind in the Tropical Stratosphere

We mention three works devoted to a recently discovered and still unexplained circulation peculiarity in the tropics, i. e., the 26-month oscillations in the zonal wind component in the tropical stratosphere, with transition from west to east. Reed /133/ investigated these oscillations at altitudes of 15—30 km during 1954—1956 and found that the oscillation amplitude decreases downwards, towards the tropopause. Similar oscillations are also observed in the temperature field. In another work Reed and Rogers /134/ studied the circulation in the tropical stratosphere during 1954—1960 from 23 stations in Southeast Asia and in the Pacific Ocean, for the purpose of investigating the same 26-month wind cycle in the equatorial stratosphere. Angell and Korshover /135/ studied the same oscillations on the isobaric surfaces from 50 to 10 mbar at many stations between latitudes 30° north and 30° south and established a number of their peculiarities.

11. Jet Streams

We mention separately works on the climatology of jet streams. Ponomarenko /136/ studied seasonal variations in the position of planetary high-altitude frontal zones, that is, essentially of jet streams, over Europe and West Siberia during 1950—1958 and found a good agreement between them and the seasonal peculiarities of the cyclonic activity. Crossley /137/ studied the distribution of jet streams at 200 and 300 mbar over the Atlantic, Europe and the Mediterranean Sea during 1957—1958 and plotted seasonal-mean frequency maps, frequency rose maps over quadrants and others. Leskova /138/ published a work on tropical jet streams over the Far East during 1958 and 1959 on the basis of an analysis of AT-300 and AT-200 mbar maps. Monthly maps were plotted of jet stream axes, their frequency and wind velocity over East Asia for the mean months of the seasons.

Krishnamurti /139/ studied the winter subtropical jet stream over the whole terrestrial globe from AT-200 mbar maps. He observed that the jet stream forms a continuous belt around the earth with three sinusoidal quasi-standing long waves and with a mean axis position oscillating between 20 and 35° north latitude. The velocity at the axis is on the average 250 km/hr; over Japan it is up to 370 km/hr.

Finally, Phillpot /140/ gave a picture of the averaged western jet streams in the Southern Hemisphere by means of vertical profiles of the temperature and of the zonal wind components along the meridian from 25° south latitude up to the pole, and upwards—up to 50 mbar. Two latitudinal wind maximums are observed.

12. Cyclonic Activity

Cyclonic activity in extratropical latitudes is the most important climate-forming factor in the general circulation of the atmosphere. During the period under consideration we may mention in this respect a number of works. Reed /141/ set up on the basis of observations during 1952 — 1956 a scheme of the summer circulation in the Arctic, indicating the formation of a secondary front at the coasts of Siberia, Alaska and Canada. The cyclones of this front often penetrate into the Arctic, and a semi-permanent anticyclone does not exist there (the conclusion of course is no longer new). In D'yachenko's work /142/ types of synoptical processes are noted during storms of the southwestern direction on the Murmansk coast. Ragozin and Chukanin /143/ studied the prevailing cyclone trajectories in the Arctic during the main circulation forms. Il'inskii and Egorova /144/ dealt with cyclonic activity over the Okhotsk Sea in the winter half year (1953—1959), and Karpova and Svinukhova /145/ over the Bering Sea (1955—1959).

Using the zonal and meridional circulation indices, Gromova /146/ studied circulation peculiarities over East Siberia and over the adjacent part of the Pacific Ocean up to an altitude of 100 mbar. The variation in the indexes with latitude and with altitude is shown.

In the work of Napetvaridze /147/ types of synoptical processes determining the climatic regime in Georgia are indicated. Balabuev and Shelkovnikov /148/ also studied the peculiarities of the circulation regime in Zakavkaz'e (during 1950—1954) by means of vertical profiles.

Vitvitskaya /149/ investigated southern cyclones and storms over the Black Sea in the warm half-year of 1949—1950 from data of 24 stations. Emm /150/ and Arifkhanova /151/ studied high-altitude winds in Central Asia during western incursions in the cold half-year (53 cases during 12 years) and south-Caspian cyclones (72 cases during 12 years).

Hupfer /152/ considered the multiannual circulation oscillations in Central Europe as related to the annual temperature march. The periods 1901—1930 and 1930—1960 were compared. In the first period the outlines of zonal and in the second period the outlines of meridional circulation appeared sharply. In the second period a rise in the summer temperatures was observed as compared with the first period, —due to variations both in the circulation, and in the accumulated radiation.

In a detailed investigation Reinel /153/ considered anticyclone paths over Europe as a climatologic problem.

Koppány /154/ studied the formation of blocking anticyclones in West Europe in different seasons from the 5-day variation in pressure and temperature in Budapest during 1949—1952 (92 cases). Stefanov /155/ dealt with the synoptical situation of strong precipitation and cooling in Bulgaria (142 cases from 50—60 stations during 1946—1955) and established by means of AT-700 and AT-500 mbar maps five types of synoptical processes corresponding to these phenomena. Péczely /156/ gave a detailed climatic account of macrosynoptical situations over Hungary.

Imada /157/ investigated the change of seasons in Japan as connected with the Aleutian stratospheric anticyclone. It turns out that in the middle of October a well pronounced anticyclone is observed at the 25 mbar surface over Alaska, creating a corresponding rearrangement of the pressure field in the troposphere and at the surface. As a result, in Japan low circulation indexes are replaced by high ones and a transition from autumn to winter occurs.

Sugimoto /158/ studied blocking anticyclones over the Pacific Ocean at the 500 and 300 mbar surfaces.

13. Monsoons

Meteorologists of Asian countries (and not only of Asia) continued to manifest a growing interest in the study of monsoons as a link in the general circulation of the atmosphere, and of great climate-forming importance for large areas of our planet. Heyer /159/ returned to the problem of the definition of the concept of monsoon itself in the most general form, and after an examination of the history of the problem considered Khromov's definition correct, based on rigorous criteria of the wind regime, but not assuming a definite genesis of the phenomenon.

Vitvitskii /160/ studied the synoptical mechanism of the summer monsoon in East Asia as connected with the variations in the heat balance of the continent and in the thermal contrast between sea and land during the year.

Rangarajan /161/ investigated from radiosonde observations the thermal effect of the Tibetan plateau on the development of the summer monsoon.

Ananthakrishnan and Krishnan studied the synoptical mechanism of the southwestern monsoon in the layer from 850 to 100 mbar during 1956—1960 /162/ and found the discontinuous variations in the state of the monsoonic regime in June and October to be connected with transformations of the atmospheric circulation on the scale of the whole hemisphere, i.e., in a sense with the variations in the position of the planetary wind zones.

Koteswaram and Bhaskara /163/ published a synoptico-aerologic investigation of the three-dimensional structure of the summer Indian monsoon in the troposphere, and in the lower stratosphere, from data of the International Geophysical Year. Circulation systems connected with the beginning and withdrawal of the monsoon and with oscillations in its intensity were investigated. Rao /164/ calculated the meridional transport of mass, heat and momentum by the summer Indian monsoon from data of 1956.

Berson's work /165/ considers the mean meridional circulation at the time of the Indonesian-Australian summer monsoon.

Connected with the monsoonic circulation character in East Asia is also the well-known climatic bai-u season, always a point of interest to Japanese meteorologists. Yamamoto /166/ investigated the variations in the synoptical situation in the bai-u season over a large region of Asia. Suda /167/ gave an account of the bai-u season from mean 15-day isobaric surface contour maps during 1947—1957. Otsuka /168/ studied the synoptical situation of the beginning of the bai-u, Midzukosi /169/—the distribution of precipitation on bai-u fronts, and Miyauti /170/—the weather following the end of the bai-u season.

14. Tropical Cyclones

A number of works on the climatology of tropical cyclones, in particular typhoons, may also be mentioned. Arakava and Tati /172,171/ carried out a large statistical investigation of typhoons in the western part of the Pacific Ocean from observations during 1940—1959. Altogether during this period 561 typhoons were observed (on the average 28 per year) of which 90 occurred over Japan. We note incidentally that during the last 30 years the number of North Atlantic hurricanes is determined as 10 per year, i. e., more than given by investigations for the preceding period. It is very likely that we are witnessing here an improvement in the observation network.

From synoptical maps of the U.S. Weather Bureau for 1920—1938 and from the bulletins of TsIP from 1947—1957, Egorova /173/ studied typhoons emerging from the region of the Philippines, with respect to the distribution of focii, frequency and duration of existence. She investigated altogether 253 cases. Kavanabe /174/ plotted frequency charts of typhoons over months during 1912—1960. Tonaka /175/ investigated winds and rains in the Oita prefecture as dependent on typhoon trajectories during 33 years from 1926, and Kasamura /176/ —the wind conditions over all Japan created by the passage of typhoons along different trajectories.

Orgill /177/ examined the relation between the monthly circulation indexes and the anomalies in the development of typhoons.

The frequency of tropical cyclones in the central Atlantic (to the north of the greater Antilles) during 1886—1961 was studied by Lange /178/. Altogether he was able to count 154 hurricanes and 112 gales (with a wind velocity from 17 to 32 m/sec). Jordan and Ho Te-chun /179/ studied variations in the annual frequency of tropical cyclones in 1886—1958 both over the North Atlantic, and over the east of the Pacific Ocean, and arrived at the conclusion that these variations from year to year are random and do not display any clear relationship to solar activity.

15. Tornadoes

Of the numerous works on tornadoes Wolford's study /180/ of the distribution of tornadoes over the USA from data of 1916—1958 is of climatologic value. During this time 9167 tornadoes were recorded, of which 1041 were in Kansas. The mean annual number of tornadoes is 213, the maximum number in 1957, 864. The average annual number of days with tornadoes is 79. The mean path length is about 8 km, and in individual cases up to 600 km. The mean trail width is 230 m. Wind velocities up to 125 m/sec have been observed. Higher ones probably occur. The lowest pressure was 912.4 mbar.

16. Air Masses and Fronts

Only three works can be indicated which are devoted to types of air masses and fronts in the climatologic aspect. Berkes /181/ published a paper on types of air masses and fronts in the Carpathian Basin. In Brazil a work by Serra and Ratisbonna /182/ on air masses of South America was reissued. Their types, sources and relation to the general circulation are clarified.

In Japan, Nagao /183/, working on the spatial distribution of variability in the basic meteorological elements, determined the effect of air masses of different origins on the climate of Japan in winter and summer.

17. Other Works on Atmospheric Circulation and Climate

We mention separately several works on important subjects connected with the general circulation of the atmosphere and with climate formation. Hesselberg /184/ published maps of climatic deviations for Norway and gave an analysis of the deviations of the seasonal means in individual years from the multiannual means of 1901—1930. The isolines on these seasonal deviation maps (altogether 120) are compared with the mean component of a gradient wind.

There are three works on the problem of the interaction of the ocean with the atmosphere as factors of climate formation. Bjerknes /185/ studied the variations in the annual-mean pressures in Iceland and in the Azores and the pressure difference between these regions, and compared them with the temperature anomalies at 6 points. Roden /186/ studied the statistical relations between the water temperature, the cloudiness and the wind in the North Atlantic during 1906—1913 and 1922—1938 for 8 regions of the Atlantic (according to Bullig's atlas). Semenov /187/ also studied the interaction of the atmosphere and the hydrosphere for the North Atlantic (the temperature field in the ocean, its relation to the preceding circulation and its importance for the variability of the air temperature and of the relative topography of 500—1000 mbar).

Some investigations were also published concerning the problem of orographic effects on the circulation and through it on the climate. Steinhauser /188/ studied the influence of the Alps on large-scale air currents from radio-sonde ascents in Vienna and Munich (6500 observations). A variation in the wind flow in Vienna up to an altitude of 3000 m and more has been ascertained. Kletter /189/ dealt with the disturbing effect of the Alps on the sequence of circulation types at moderate and high latitudes of the northern hemisphere by means of circumpolar AT-850 mbar maps for a number of years. Koshinskii /190/ studied the influence of coastal orography on the wind regime of the Caspian Sea at the time of northwestern gales.

18. Aeroclimatology

Here it is appropriate to mention some works on the climatology of high layers of the atmosphere (in addition to the above- mentioned investigations of the wind at altitudes). Dubentsov /191/ investigated the temperature distribution up to an altitude of 100 km and gave the corresponding maps for 4 months of the year and for the layer from 200 to 10 mbar. Kvartskheliya's work /192/ deals with the climate of the free atmosphere over Georgia, namely: the regime of the temperature, pressure and humidity from radiosounding observations in Sukhumi and Tbilisi in 1938—1952, as well as of the wind from several pilot-balloon stations. Chestnaya /193/ considered the vertical distribution of the temperature and of the specific humidity from airplane observations over the Sevan basin in comparison with Erevan. Hosler /194/ investigated the frequency of inversions and isothermies in the USA from radio-sonde ascents in the layer up to 150 m, from observations on towers and at mountain stations.

Some works are devoted to the statistics of the tropopause. Churinova /195/ studied the dependence of the altitude of the tropopause on the surface pressure and on the altitude of the 500 mbar surface from radio-sounding observations at the station "Severnyi polyus 7" and on Kheis Island in 1957—1958. Fedorov /196/ described the tropopause over the Oazis station in Antarctica. Burkova and Islamova /197/ studied the topography of the tropical tropopause over Central Asia in the summer of 1958—1959. They found, incidentally, that its altitude varies from 14.1 to 17.6 km, increasing from north to south, and the temperature drops from −56.8 to -70.4°. The maximum wind layer is situated on the average under the tropopause. Greenfield /198/ carried out a statistical investigation of the tropopause over the tropics of the Pacific Ocean (altitude and temperature of the tropopause over the Marshall Islands, the wind structure in the region of the tropopause); Miloshev and Kamenov /199/ gave an aeroclimatic account of the tropopause over Sofia. Borbély /200/ studied the interdiurnal variations in the altitude and temperature of the tropopause over Budapest.

We mention separately the work of Selitskaya /201/ on the diurnal and annual variation of the meteorological elements over Voeikov in the lower 500 m done from balloon ascents in 1958—1960.

A number of works appeared on the technique of climatological processing of aerological observations, carried out mainly in the Institute of Aeroclimatology in Moscow. Works /202—207/ considered the problems of the plotting and analysis of high-altitude maps of the temperature, altitude of isothermal and isobaric surfaces, specific and relative humidity, density, wind and mean air transport. The techniques of determining the tropopause boundaries from the criteria of VMO and of NIIAK were also compared.

19. Moisture Circulation

We mention now some works on the third cycle of climate-forming processes—moisture circulation. Bushmanov /208/ investigated the ratio of precipitation to evaporability in Central Ural from April to October for 40 stations. The evaporability was determined by N. N. Ivanov's formula. Maps were plotted of the mean humidity for each month. Kuznetsov /209/ studied the humidity of the western regions of the Ukraine during 1945—1955, using Ivanov's humidity coefficient; maps were plotted for the warm period and for the whole year. Sorochan /210/ searched for quantitative characteristics of moisture transport in days with a stationary Siberian anticyclone (winter monsoon, breakdown of the summer monsoon) during 1957—1958 over temperate latitudes of Asia. Smekalova /211/ determined the quantitative characteristics of the moisture circulation components in the Black Sea Area during 100 humid periods in 1946—1957 by using radio-sounding data. The coefficients of moisture recovery, that is, the ratio of the precipitation amount to the amount of transported moisture, were calculated.

Drozdov /212/ calculated the coefficients of the hydrologic cycle for temperate latitudes of Eurasia. Water vapor transport over Japan at the surfaces from 1000 to 400 mbar during 1951—1955 was investigated by Mukai /213/. Maps of the integral transport were plotted and the origin of the transported moisture was explained. Hutchings /214/ studied the transport of water vapor over the Australian continent from daily wind and humidity observations at 8 levels, from the terrestrial surface to 400 mbar, for 17 aerologic stations.

We note in passing works on the evaporability regime. Seryakova /215/ calculated the annual and monthly evaporability amounts at 16 stations in Crimea and at 24 stations in the Caucasus by the GGO method (from the radiation balance, the humidity deficit and the air temperature). The annual amounts were found to be from 670 to 850 mm in the Crimea (Southern Crimean coast) from 600 (on the coast) to 700 mm in the Caucasus.

Bertossi /216/ calculated the distribution of the total evaporability from 170 stations of Italy for the period 1921—1935 by Thornthwaite's formula, and plotted distribution maps of the humidity and dryness indexes.

20. Temperature Regime

Concerning the temperature regime of the atmosphere we mention only a few works which are the most thorough or have the largest time or space scale.

Thus, Berseneva /217/ plotted world maps of the dates of the beginning and end of frosts, and of the duration of the frostless period. Popescu-Dumitrescu /218/ studied the frequency of various values of the diurnal-mean temperatures in Bucharest over a period of 60 years, and Miloslavlevich /219/ —hot days in Belgrade over 75 years.

Babushkin /220/ used multiannual data to examine the temperature regime of the cold months of the year in the republics of Central Asia. Szakácsné's work /221/ studied the diurnal variation in the air temperature in different districts of Hungary. Hartmann /222/ investigated temperature oscillations in the northern hemisphere at the 500 mbar surface during 1958—1960 by means of an original technique.

Noteworthy are Zemlyakova's works on the frequency of fogs over the Black Sea /223/ during 1880—1958 observed from vessels and coastal points, as well as the work of the Englishman Schloss on cloudiness in the USSR /224/.

21. Microclimate

Of the large number of microclimatic works we mention first the report /225/ on observations at a dense network in Arizona in July 1960. On an area of 55 × 75 km, 33 microbarographs, 10 hydrothermographs, 10 anemographs, and 165 rain gages were arranged. Cloud formation and precipitation fall were investigated in relation to the relief of the terrain.

The influence of irrigation and sprinkling on the microclimate in the given and in the surrounding regions was investigated by Kolobov /226/ for the Kuibyshev water reservoir (it was found that microclimatic variations are felt at a distance up to 5—6 km from the reservoir). Kolosnik made a similar investigation for the Ukraine (results of microclimatic investigations on irrigated steppe farms had been made in 1962). De Vries and Birch /228/ did one in Australia. The influence of irrigated pasture grounds on the microclimate was also determined.

The microclimate of the forest was studied by Rauner and Dzerdzeevskii /229, 230/ on the basis of gradient observations near Moscow and by Myachkova /231/ from expedition observations in the southwestern part of the trans-Baikal region. Vil'kens and Shakhnovich /232/ published results of microclimatic investigations in the grape region of trans-Carpathia during 3 years.

The influence of forest belts on wind and on turbulent exchange is summarized in the work of Konstantinov and Vorontsov /233/.

Dubinskii et al. published results of microclimatic observations on Caucasian glaciers /234, 235/. Matyukhin /236/ published climatic data for 8 years at 4 stations on the southern slope of El'brus from 2146 to 4200 m. Microclimatic investigations are also given for a number of regions, such as the sand plains of Brazil /237/, Central Dnieper area (Shcherban' /238/), the beaches of the health resort of Varna (Petkanchin, Kirov /239/), Alaska, Trans-Ili Alatau, the Alps, El'brus and many other regions.

Timofeev /240/ determined theoretically the variations in the heat balance components on the surface of a water basin in comparison with the land, and the extent of the influence of the basin on the climate of the surrounding territory. Another work by the same author /241/ proposes a technique for calculating the temperature and humidity variations due to the influence of water basins.

22. Climate of Towns

We mention separately works on local climate and on the microclimate of towns. A third part of the monograph on the climate and microclimate of Vienna (Steinhauser et al. /242/) dealt with the wind, precipitation, air contamination and climate of the streets. From a series of observations made over 60 years (by means of moving averages) Mitchell and Murray /243/ examined the temperature regime of Baltimore and found a gradual rise in the temperature as the town grew, particularly at night. In Tokyo (Vada /244/) the temperature rise during 1942—1959 as connected with the town's growth was investigated from 15 points.

Serkowski and Stodolkiewicz studied the climate and microclimate of the surroundings of Warsaw /245/. Miloslavljević /246/ compared the air temperature and humidity in Belgrade and in its surroundings (newly built-up regions) from simultaneous four-year observations. De Marrais /247/ studied the temperature distribution over Louisville (Kentucky) up to an altitude of 150 m by using a television mast, and found important differences in the stratification between the town and the open terrain.

Jauregus /248/ gave an account of the climate and microclimate of the health resort town of Cuernavaca in Mexico.

Numerous studies have been made of the contamination of town air—in Los Angeles (Grieswold /249/), in Washington (Stockman /250/), in Prague (Spurny /251/), in Nowa Huta (Gastol /252/), in Lodz (Róznański /253/, in Upper Silesia (Paszynski /254/), in Helsinki (Jormalainen /255/), in Perm (Maksimovich /256/), in Budapest, Ottawa (Munn, Ross /257/) and others. It was found that in Los Angeles up to 40 tons of aerosol, 450 tons of sulfuric oxides and 190 tons of nitric oxide enter the air every day /249/. In the territory of Upper Silesia up to 300 tons of contamination is deposited daily from the air, and the amount of SO_2 is 4, 8 and even 20 times higher than the permissible limit /254/. In Perm 25—50 thousand m^3 of dust is deposited annually /256/.

23. Current and Historic Climate Variations

We pass to the problem of climate variations. The interest in climate variations during past and present epochs does not diminish. We mention a number of papers on current temperature rise and on the climate of the period of instrumental observation. Mitchell and Murray /258/ found that the rise reached a maximum in the 40's, after which the temperature began to fall. A temperature rise took place also in the tropics. In the southern hemisphere the annual-mean (but not the winter) temperatures increased.

Buchinskii /259/ investigated the temperature from 12 stations and the precipitation from 30 stations of the Ukraine for periods from 60 to 150 years, and by means of moving averages observed a warming from the second half of the 19th century, with intensification in the 20's of this century. In the 30—40's of this century, precipitation sharply decreased. In the last decade precipitation shows a tendency to increase.

Rocznik /260/ studied the sequences of mild winters in Europe during 200 years from 1761, and established an increase in the number of such sequences since 1900. Knoch /261/ studied warm winters in North Germany since 1766 from the totals of negative diurnal-mean temperatures in Berlin, and Brose /262/ studied the severity of winters in Western Germany from 1826 to 1961.

Keil also /263/ investigated the air temperature in Hoen-Peisenberg over years, seasons and months during 180 years, by means of 30-and 60-year moving averages.

The changes in Zonblik's glaciers as connected with the climatic regime since 1850 were studied by Tollner /264/.

Suda /265/ studied mild winters in Japan in recent decades and indicated that the general rise in temperature in the whole country became particularly noticeable from 1945 against the background of the recent increase in the number of sun spots. He related these temperature variations to the secular variations in the pressure distribution on the Far East — surface and AT-500. Dzerdzeevskii /266/ compared the variations in the temperature and in the precipitation at high latitudes of the northern hemisphere during 50 years of this century with the variations in the general circulation of the atmosphere. It was found that in the first 35—30 years meridional, and in the second 25—30 years, zonal circulation prevailed. However, Hupfer /267/ arrived at the opposite conclusion for Central Europe when he compared the periods 1901—1930 and 1931—1960. We note in passing that Wege /268/ found from an analysis of the temperature, pressure and precipitation in the Atlantic-European sector of the hemisphere, an increase in the continentality of the climate from 1901—1930 to 1930—1960. Incidentally, the pressure gradient between the Azores and Iceland decreased from the first to the second period by 7 mbar.

Yamamoto /269/ compared the second half of the 19th century and the first half of the 20th century with respect to temperature and precipitation and found that the equatorial rain belt narrowed during this time and the desertes of temperate latitudes expanded. In the last 10 years the opposite tendency was observed. Precipitation in Seoul in May and June is positively correlated with the relative number of sun spots, whereas jet streams are negatively correlated.

Multiannual variations in the continentality of the climate of West Europe were studied by Spirina /270/ from the 10-year moving average from 1881 to 1950. According to Spirina's conclusions, the latitudinal temperature gradients between marine and continental stations, according to monthly-mean data smoothed over decades, oscillate with a periodicity of 18—20 years on the west. On the east of the region the oscillations are close to Brikner's cycle.

Kononova /271/ determined the boundaries of the natural seasons for East Siberia during two decades: 1906—1915 and 1944—1953. She arrived at the conclusion that in the second decade the frequency and intensity of the zonal circulation increased.

The annual variations in continentality in Japan were studied by Noro /272/ during the period 1900—1950.

Duginov /273/ studied the climate oscillations in the steppe and forest steppe zone of the European part of the USSR during the last 60 years by means of moving averages and established a periodicity of 10.8 years for a number of elements. For other indexes, such as the annual-mean temperature, the connection with the solar cycle was maintained until 1920—1922, but was then inverted or the curves became double-vertexed. Karapiperis /274/ investigated the temperature variability from 30-year moving averages for Rome and Athens and also established the relationship with solar activity. Willett /275/ pointed out the relation of the climate to the 80—90-year cycle of solar spots on the basis of a comparison of the maps of the pressure distribution at sea level, the contour of the 500 mbar isobaric surface and the temperature variations.

Kostin /276/ studied the climate oscillations in the Voronezh region from an analysis of the growth of an oak's thickness from 1730 and observed a period of about 80 years in the precipitation oscillation. The frequency of droughts on the Russian Plain during the last 150 years was studied by Vazhov /277/. Shnitnikov /278/ found the dampness of the southeast of the European part of the USSR to have a cyclic character during the last 80 years, judging from the annual precipitation amounts, the indexes of the total dampness and the level oscillations of small water basins. According to Shnitnikov's conclusions from the 70's of the last century, the third phase of increased dampness which began in 1955 has already taken place and has now reached full development.

Troup /279/ studied the relation between secular variations in the cycle of sun spots and the temperature of the tropics. Until 1920 at the maximum of sun spots the mean air temperature in the tropics was lower than at the minimum, out round about 1920 the negative correlation was replaced by a positive one. The relation between solar activity and other climate elements also changed. From this the author concludes that the previously established relation between climatic variations and the 11-year cycle of sun spots was accidental, and that the indicated temperature oscillations are of terrestrial origin.

Muller-Annen /280/, on the other hand, arrived at positive results when he compared the weather conditions in Europe with solar activity over 109 years.

Schell /281/ compared the ice on the coasts of Iceland with the climate during the last 1200 years, and Lamb /282/ summarised climate variations on the terrestrial globe since 1750 on the basis of an analysis of circulation conditions (from pressure distribution maps). The periods 1890—1909 and 1919—1938 are also compared in the work. The work of Lamb and Johnson /283/ is devoted to the same subject.

24. Geological Climate Variations

We mention only a few of the large number of works on the climates of the geological past . Pewe /284/ studied climate variations in Anctarctica in the Quarternary period from glacial activity. Karlstrom set up in a major work /285/ the chronology of the Pleistocene glaciations of Alaska from glacial deposits, and related it to the assumed paleoclimatic variations. Ewing and Donn /286/ investigated the climate variations in the Pleistocene on the basis of an analysis of the alternation of ice-free and ice-covered sections of Arctic seas, assuming that the free sections had been maintained from the Pleistocene period. Donn /287/ investigated the climate variations in the Pleistocene from an analysis of deposits taken from large depths in oceans and seas. Ericson /288/ proposed climatic characteristics of the Pleistocene also from deep-water deposit samples about 200 of which had been obtained in the North Atlantic over a period of 18 years. Taylor /289/ gave a chronology of the development of vegetation during the last 12,000 years by means of pollen analysis and analysis of C^{14}. Pollen and radioactive carbon analyses were also used by other authors for studying the climate variations in North Iraq, New England (USA) and other places. We will not give references to these works.

Sakaguti /290/ studied the climate variations in North Japan in the Holocene. He points out that the warm period, about 1000 years B. C., corresponds approximately to the climatic optimum in Europe. Emiliani /291/ considers the climate variations in the Cenozoic era, determining them from the stratigraphy and chronology of deep-water globigerina sediment.

In a large work, Faibridge /292/ compares glaciation data, beginning from the Pre-Cambrian period, and gives numerous interpretations of them. He comes to the conclusion that temperate latitudes will continue to ice and de-ice periodically every 40—90 thousand years.

Schwarzbach /293/ gave a review of the climates of Europe and of North America in the Paleozoic, Mesozoic and Cainozoic eras. He points out that on both continents there has been a warm climate mainly during the last 500 million years, but, in general, a drier one than at the present time. At the beginning and end of this period there were glaciation periods with a large spread of glaciers.

Albrecht /294/ draws conclusions from paleoclimatologic data on variations in the heat balance during a number of geological periods up to and including the Carboniferous.

Sabels /295/ sums up on climatic variations in the tropics of the Pacific Ocean from results of an analysis of the traces of chemical elements found in caves on the Marquesas, Hawaian and other islands.

Bacsák /296/ outlines in a large work a picture of the climates of the equatorial zone in the past, based on assumed astronomical causes of the climate variations.

Runcorn /297/ points out that paleomagnetic data indicate that throughout the earth's history the position of the poles changed and the continents drifted. Accordingly the latitudinal position of the continents changed, a finding which is in good agreement with the climate variations. Between the Devonian and Triassic periods Europe and North America were situated at low latitudes.

In conclusion we mention the monograph "Descriptive Palaeoclimatology" /298/ edited by Nairn, in which 15 authors took part, as well as the new revised edition of Schwarzbach's well-known book on the climates of the past /299/.

Numerous works on various sections of applied climatology have not been included in our review.

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Professors I. S. Berzon and P. S. Veitsman

STRUCTURE OF THE CRUST AND OF THE UPPER PART OF THE EARTH'S MANTLE FROM GEOPHYSICAL DATA

The numbers of "Referativnyi Zhurnal Geofizika" for 1962 reflect the principal trends and results of the work of Soviet and foreign geophysicists concerned with the investigation of the terrestrial crust and upper part of the mantle.

The investigation technique, different for different problems, is considered: data on the structure of the earth's crust of essentially different zones as continents and oceans, shields, continental plateaus, mountain structures, island arcs and deep-sea depressions, internal and marginal seas. The problem of the nature of deep interface boundaries is considered, in particular the boundaries of Mokhorovich (M) and of Konrad (K), as well as the problem of the composition and physical features of the so-called "granite" and "basalt" layers and of the upper part of the shell or the so-called "upper mantle."

Most of the problems touched upon do not yet have a unique solution, all being at the same time extremely important for a correct understanding of the processes which take place in the peripheral part of the earth and for creating adequately based geotectonic hypotheses. At present it is quite clear, that a coordinated and thorough study of all these problems ("upper mantle" project) has begun on an international scale.

In order that the complex geophysical data should acquire a maximum basis in geology, the drilling of a number of very deep holes is projected, some of them designed to reach the mantle rocks. In the USA such works is carried out in the oceans (project "Mohole"). In the Soviet Union several deep holes on land in widely different geological conditions are projected.

Let us consider the basic of these problems, subdividing them into the following groups:

1. Methods of investigating the earth's crust and upper mantle;
2. Structure of the earth's crust and upper mantle of essentially different zones;
3. Geological interpretation of geophysical results.
4. International project of investigations of the earth's crust and upper mantle (project "upper mantle").

1. Methods of Investigation of the Earth's Crust and Upper Mantle

Information on the stucture of the earth's crust and upper mantle is obtained by a set of geological and geophysical investigation methods.

Among geophysical methods the dominant role belongs to seismic: methods, often in combination with gravimetric and aeromagnetic methods. Seismic methods are based on the study of different classes of seismic waves, originating both in earthquakes (strong — remote and weak — local), and in explosions (very large — industrial and nuclear and specially produced — relatively small). For different sources different wave classes are used. In the case of strong remote earthquakes *P* and *S* waves are used (Petrescu, Radu, Ionescu /1/), as well as surface waves of various types. In some cases waves reflected from the surface of *M* and from the day surface are used (Treskov /2/). In the case of normal and weak local earthquakes also, *P* and *S* waves and exchange-type waves are used. In the case of explosions, refraction waves are used, refracted and reflected before and after the initial point.

The listed seismic methods naturally differ one from the other in detail, and therefore give a different description of the structure of the medium being studied.

Most widespread at present is the complex of seismic and gravimetric, and sometimes also aeromagnetic observation. By means of such complex investigation the largest amount of data on the structure of the earth's crust on land and on sea and ocean has been obtained. A comparative study of the structure of regions which differ in their history of geological development should be based on methods which give results similar in detail.

Let us consider separately the features and possibilities of the different methods.

Remote earthquakes. The use of group and phase velocities of surface waves of different types produced by remote earthquakes has become widespread, mainly for a comparative study of the structure of the earth's crust and upper mantle under continents and oceans (Press /3/). In the work of Aki Keiti and Press /4/ results are given of investigations carried out by choosing different mantle models, based on the use of group velocities. A model of the structure of the crust and of the upper mantle for the northern and southern part of the Pacific Ocean was chosen. The use of the same model for data obtained in the Atlantic and Indian Oceans gave agreement for very long-period Rayleigh waves. For other waves, discrepancies which may be due to a different structure of the mantle, in particular to a different position of the layer with reduced velocity, were obtained.

Investigations were conducted on the dispersion of surface Love and Rayleigh waves with periods of 3—10 sec, recorded by the seismic stations in Iceland and Greenland from earthquakes of the northern part of the Central Atlantic seismic belt (Båth /5/, Tryggvason /6/). The dispersion of the observed waves agrees with the theoretical calculation for a three-layer medium. The upper layer is encountered everywhere and varies in thickness from 3—4 km, in the middle of the Atlantic Ridge to the south of South and Central Iceland, to 7 km to the north of Iceland.

The second layer, whose thickness is close to that of the first one, exists only under Iceland. The thickness of the third layer was not determined.

In the Pacific Ocean, in the region of Honolulu, long-period Press and Ewing seismographs were used (Ewing, Kuo, Brune /7/). It was shown that the dispersion curves of Rayleigh waves propagated under the bottom of the Pacific Ocean are everywhere of the same type, except in the region of New Zealand — Melanesia. In this region the velocities of Rayleigh waves are too low.

From investigations of the dispersion of Rayleigh waves in the region of the Andes, a crust thickness of the order of 50 km was determined (Cisternas /8/). Investigations in Antarctica gave a crust thickness along the axis of Graham Land of 35 km with a typically continental structure. Indications were obtained that most parts of west and east Antarctica have a crust not purely of continental type (Dyuart /9/), (Kovach, Press /10/).

These data do not contradict the opinions given in the work of Sorokhtin, Avsyuk and Kondrat'ev /11/, but somewhat contradict the opinions given in the work of Demenitskaya /12/, where it is indicated that the maximum thickness of the terrestrial crust in Antarctica reaches 65 km. More detailed work concerned with the study of the structure of the terrestrial crust in Antarctica has not been conducted. A number of studies of the structure of the terrestrial crust from surface waves were conducted in Japan (Tetsuo, Santo /13/ and Sibata /14/).

Work using surface waves for studying the structure of the earth's crust was begun in the Soviet Union fairly recently (Sikharulidze /15/).

In the case of remote earthquakes, in addition to surface waves, waves reflected from the Mohozovicic discontinuity and from the day surface are also used (Treskov /2/). In addition, in China, in the western part of the Tsaidam Basin, deep, subcrustal reflections from a depth of the order of 52 km were obtained (Tseng Yun-sheng, Kan Yung-tsou /16/).

In the Soviet Union a method has been developed for studying the structure of the earth's crust, using forward composite PS waves from remote and close earthquakes. In the work of Bulin and Sytin /17/ the basic formulas are given for determining the depth of exchange boundaries, and the equipment and technique of the work are described. The assumptions under which the calculations are made are indicated and the basic criteria for distinguishing PS waves on seismograms are formulated. It is indicated that the accuracy of the determination of the depth of exchange boundaries depends on the authenticity of the concept of velocity profile. Some results are given from the territory of Turkmenia, where two marker boundaries at depths of 12—15 and 30—45 km were discovered. A comparison is given of the results obtained, with data of other geophysical methods and of deep drilling. The necessity is stressed for further developing this method and creating for it special equipment.

Close earthquakes. During recent years greater attention was given to the use of weak close earthquakes for the study of the structure of the earth's crust and, in particular, for discovering and locating deep faults, to which, as a rule, weak earthquakes are confined. The development of this kind of method was initiated by the Institute of Physics of the Earth of the Academy of Sciences of the USSR, and later developed by Czechoslovakian scientists in Komarno. At present the method is being developed considerably also in the Soviet Union (Kiselev /18/) and abroad (Mikumo Takeshi /19/, Chakravortty, Ghosh /20/). The latter work, carried out in India, gives some information on the structure of the crust under the Himalayas. In particular, it is indicated that the velocities of P waves vary sharply in different regions, being considerably higher in the region of the Himalayas than in the south of India. Two layers are distinguished in the crust. The total crust thickness reaches 42 km for the East Himalayas, and 35 km south of the Central Himalayas. These values, on the basis of general geophysical considerations, seem underestimated.

Similar work using radiotelemetric equipment was done in southern Africa (Gane /21/). The crust thickness was estimated at 35 km from the phase of P and at 33 km from the phase of S.

Large explosions. In individual cases large explosions both industrial /22/ (Cram, Ira /23/), and in recent years also nuclear, are used as a source of oscillations for the study of the structure of the earth's crust. In the work of Berg, Cook, Narrans and Dollan /24/ a description of work on the recording of seismic waves from strong explosions and results of their interpretation are given. In investigations of the earth's crust 9 explosions with a charge from 25 to 120 tons, and also the nuclear explosions "Reinier" (1.7 ktons) and "Blank" (23 ktons) were used in the state of Utah (USA). The recording was made by one type of equipment at 17 temporary stations and with equipment not of one type at 15 permanent stations. The maximum distances from the explosion were 1000 km. Hodographs of the principal waves were obtained on which a shadow zone is distinguished. A cross section was plotted and found the first boundary situated at depth of 9 km, the second at 25 km, and the third at a depth of 72 km.

Determination of the terrestrial crust thickness from observations of nuclear explosions was also made in Australia. It was observed there that a crust thickness determined from S waves was somewhat larger than that obtained from P waves. Values of 30—40 km are given (Bullen /25/). *

Experiments in obtaining vertically reflected depth waves were made in 1955 in Kiruna. Industrial explosions with charges from 235 kg to 8 tons were used. The mean distance to the reception point was 10 km. For distinguishing the reflected waves on the recordings phase correlation was used (Båth, Tryggvason /26/).

Comparatively small, specially produced explosions. The most detailed and reliable results are obtained by methods of correlational tracing of seismic waves excited by comparatively small correlational tracing of seismic waves excited by comparatively small explosions (from hundreds of kilograms to a few tons of explosive material). Such a method has been developed in the Soviet Union, This method, called "seismic depth sounding" (SDS) of the earth's crust has additional advantages over seismic methods by virtue of the fact that the explosions occur at the time and place required by the investigator. The place and time of the focus are accurately known. A disadvantage of the method is that it is cumbersome and expensive, particularly in the case of detailed profiling. Efforts are at present being made to improve and facilitate its operation.

* This contradicts the values obtained in /21/.

A large amount of work is carried out in the Soviet Union on the method of deep seismic sounding on land, and a relatively small amount on seas and in the Pacific Ocean. A similar technique for the sea has been worked out abroad, where much work is being done on the structure of the terrestrial crust of the World Ocean. Work that is similar to seismic depth sounding is being done abroad on land, but as yet on a small scale.

Godin's work /27/, exemplifying research done on the southeastern Russian continental plateau, in Turkmenia and Uzbekistan by VNIIGeofizika in 1956—1959, demonstrates the expediency of complex seismic prospecting and of regional continuous profiles of SDS with analysis of graviational and magnetic data. The need to develop simpler methods using natural seismicity and the electromagnetic field of the earth is indicated.

Gravimetric work. The work of Gainanov and Smirnov /28/ reports the results of gravimetric work carried out in 1951—1954 in the Far East. It is concluded that the crust thickness varies from 25 to 10—15 km when passing from the continent to the ocean.

In connection with the International Geophysical Year complex geophysical research was carried out, including more detailed and precise gravimetric investigations. For the determination of the earth's crust thickness from gravity anomalies, reference SDS data were used in the Bouguer reduction. A schematic map of the M surface relief was plotted. Correlation between gravity anomalies and manifestations of the most recent tectonic motions in the region of the Kuril arc is noted.

In respect of all basic structural maps plotted from gravimetric data, with different averaging methods, the author stresses the necessity to take the reference depths on the basis of seismic data. However, despite this, all these kinds of plottings are largely ambiguous (Demenitskaya /29/, Volodarskii /30/, Tomoda /31/, Balavadze and Shenguelaia /32/, Tatevosyan /33/). Often, in the plotting of maps, the step between the isolines is too small, not corresponding to the possibilities of the method.

In /29/ an empirical formula for determining the thickness of the earth's crust by conversion of gravity anomaly maps to the Bouguer reduction is given. It is stated that from the averaged curve of the dependence of the gravity anomalies on the thickness of the earth's crust, the thickness of the latter in any place can be determined. However, the possibility that isostatically unbalanced regions exist not obeying the general averaged regularity, is not taken into account.

A number of works consider the problem of the relation of the depth of the M surface with the relief of the terrain and with gravity anomalies. The authors approach this problem in different ways. In Demenitskaya's work /34/ use is made of data of a world gravimetric survey and of reference seismic data for finding peculiarities in the structure of the terrestrial crust on a planetary scale. In Grushinskii's work /35/ the problem is solved for the averaged relief and for the averaged gravity anomalies. On the basis of extensive statistical material, it is shown that for plain regions of the continents and for some shallow parts of the oceans, the obtained dependencies on the anomalies in the Bouguer reduction are identical to the dependencies on the relief. Shown also is the absence of a relation between the depths of the M surface and the free-air effects. It is concluded that the degree of isostatic compensation of the crust is high. The work of Shor and Fisher /36/ gives results of a study of the terrestrial core in the region of the Central-American oceanic trench and indicates that the obtained data are in good agreement with the data of seismic investigations of the Tonga and Puerto Rico trenches and do not agree with the interpretation of the gravimetric data for these trenches. This fact finds confirmation in subsequent works, from which it seems that a high degree of isostatic compensation exists only in the case of very large averagings, and if individual regions are considered, then such places as island arcs and deep-sea trenches. In particular, in the Puerto Rico trench, considerable deviations from isostatic compensation are observed. This fact shows that the use of the method proposed in the works /29/ and /34/ for a number of oceanic regions, is unbased and may lead to serious errors in general constructions.

2. Structure of the Terrestrial Core of Intrinsically Different Zones

Abundant data are given on the structure of the terrestrial core, obtained from seismic, and sometimes also from a complex of geophysical methods — magnetic, gravimetric and geothermal.

In the first place the important difference in the structure of the terrestrial crust of continents and of oceans is pointed out (Ewing /37/). The thickness of the terrestrial crust of the oceans far from continents is of the order of 5 km. As a rule, it consists of one layer, in which the velocity of longitudinal waves is about 6—7 km/sec. This layer is covered with a layer of sediments with a velocity of about 4.5 km/sec and by another thin layer with a velocity of about 2 km/sec. A layer of sediments with the higher velocity is missing in a number of places. The thickness of the sediment layer with low velocity does not exceed 1 km over large water areas. In the shell under the crust the velocity of longitudinal waves is higher than 8 km/sec.

The heat flux through the ocean bottom is approximately the same as through the surface of the earth on the continents. An anomalously high flux is observed in regions of a lifted position of the M surface, and anomalously low flux in regions where it sank. * This contradicts the assumption that the M surface is connected with the phase-transition boundary of the material.

From the character of the variations in the magnetic field in regions of deep falls in the Pacific Ocean the existence of horizontal displacements has been established.

The terrestrial crust under the continents is characterized by at least a three-layer structure. The thickness of the upper sedimentary layer strongly varies from place to place, its underlying layer having a longitudinal wave velocity of 6—6.5 km/sec. In the underlying rocks the velocity reaches 7 km/sec. Below the M surface, the velocity is higher than 8 km/sec. The thickness of the terrestrial crust under the continents is 30—50 km. A study of the dispersion of surface waves indicates the presence of a layer with reduced velocity in the upper mantle.

* At the present time, according to new data (Ewing, M., Submarine Geophysics. Trans. Am. Geoph. Un., 1963, 44, 2) it has been established: 1) the mean heat flux through the ocean bottom is greater than through the surface of the continents; 2) the system of the internal world mid-oceanic ridge is characterized by a maximum heat flux near the axis of the ridge. On the wings of the ridge the heat flux amounts to 1.5—2.0 times the mean oceanic level. In the Pacific Ocean a large diversity in the intensities of the heat flux is observed.

In works in the transition zone from the Asian continent to the Pacific Ocean (Veitsman, Gal'perin, Zverev, Kosminskaya, Krakshina /38/, /39/. /40/, /41/, /42/, /43/, /44/) mobile explosion points and two or three stationary receiving stations were used. The receivers were single, hydrophones placed in the water. In the case of one run of the explosion sheet, a system of counter and overtaking travel-time curves was obtained at once. The interval between observation points was 3—5 km. In these studies information was obtained on the sedimentary layer and on the layers constituting the crust within the boundaries of the Okhotsk Sea shelf, deep-sea trough, breaker and adjacent part of the oceanic bed. The central part of the Sea of Okhotsk has a sedimentary cover which varies in thickness from zero to 3 km. A sedimentary layer more than 5 km thick was detected at the northern Kuril islands, at the northern part of Sakhalin, in the northern part of the Sea of Okhotsk and in the southern deep-sea part of the Sea of Okhotsk. In the Pacific Ocean, in the shelf zone and on the western slope of the deep-sea trough the thickness of the sedimentary layer varies fairly strongly, exceeding in individual cases 3 km. On the eastern slope of the trough and in the ocean the thickness of the sediments does not exceed 1.5 km. The velocity of longitudinal waves in the sediments is 1.8—2.0 km/sec; a layer with a velocity of 4.5 km/sec is distinguished only in individual, fairly clearly localized places.

In these works, in addition to the typically continental and oceanic crust, another crust of an intermediate type was found, which in turn can be subdivided into a closer-to-the-oceanic and a closer-to-the-continental one. It should be noted that the most complex and diversified areas of the crust structure are the regions of the shelf and of the western slope of the deep-sea trough.

A somewhat different investigation technique in the ocean, closer to the method of seismic prospecting in the sea (MOV and KMPV), using a bar with receivers ~2 km long, is described in the work of Savit, Blue and Smith /45/. In this work the depth of the ocean is determined and a number of boundaries, being at the same time reflecting and refracting, were defined. Diffracting edges apparently confined to deep faults were revealed. It is noted that most useful for the study of the structure of the terrestrial crust of oceans would be a combination of this kind of prospecting technique and the usual technique with single suspended hydrophones.

Woolard and Hersey /46/ point to the similarity of the structure of the earth's crust in regions of island arcs between South America and Antarctica and in the Caribbean Sea, as well as in deep sea troughs, filled with sediments, on the eastern coast of Argentine, the southeast coast of the USA and of Canada. The rule of the correspondence of a thin crust to large sea depths is confirmed in a number of regions, even in regions surrounded by continental platforms, e.g., in the western and eastern parts of the Mediterranean Sea and in the region of Tuamoto. However, in the island arcs of America this rule is violated. New data have been obtained supporting the idea that the crust falls extend from the region of the Atlantic ridge through the Indian and Pacific Oceans. It is shown that anomalous velocities, obtained in works in East Iceland, are connected with an increased heat flux, and the increased velocities in the Black Sea and in the Aden Gulf are apparently due to the existence of deep intrusions, possibly of subcrustal material.

Study of the structure of the terrestrial crust in the region of the Central Atlantic oceanic basin showed that the thickness of the basalt layer varies there from one to one-and-a-half times the normal basalt thickness under the ocean (5 km). Along the axis of the underwater ridges there is a deep rift several kilometers wide. The formation of a planetary system of rifts is connected with the expansion of the earth and with subcrustal currents (Starnes /47/).

In the work of I. Ewing, Antoine and M. Ewing /48/ results of the study of the terrestrial crust in the western part of the Caribbean Sea and in the Gulf of Mexico are given. The thickness and structure of the terrestrial crust in the region studied are highly diversified. The general regularity is: correspondence between sections of a thick crust (20—25 km) and regions of uplifts and of underwater ridges, as well as the shelf zone; crusts of medium thickness — to regions of troughs, crusts of small thickness (10 km) — to the deep-sea zone. The part of the Yucatan and Colombian basins has a crust whose structure is close to the oceanic. Under submerged ridges and uplifts the crust is close to the continental type. In most parts of the Gulf of Mexico the crust is of the oceanic type.

Seismic work was done near the western end of the deep-sea Puerto-Rico trench, in the region of the assumed location of the well, which should reach the mantle rocks (Northrop and Ransone /49/). In these works 5-layers were distinguished under the 5-kilometer water mass: first — loose sediments about 4 km thick with a longitudinal wave velocity of 1.7 km/sec; second — probably metamorphozed sediments with a thickness of 1.5 km and with a velocity of 3 km/sec. Below lie two layers of crystalline rocks 2 km thick each with velocities respectively of 5.5 and 7.1 km/sec. Next follow the mantle rocks with a velocity of 8.1 km/sec. The depth up to the M surface varies from 9 to 12 km. The part with minimum crust thickness is situated 100 km to the north of the trough.

In Krishnan's work /50/ existing opinions on the structure and development of island arcs, mainly adjacent to Southeast Asia, are mentioned. The development of these island arcs is considered as a process of growth of the Asian continent in the eastern and southeastern directions. The boundaries of Asia are outlined by a "series" of arcs developing along the periphery. The internal zones of the island arcs are considered as the most ancient. The structural features of the arcs are due to compression resulting from the displacement of India and Australia. The existence of large thrusts confined to zones of island arcs is noticed.

Some regions, in particular the trough under the Ganges valley, from the foothills of the Himalayas, were studied by means of aeromagnetic methods. It is assumed that there is a large thickness of sediments. This is indicated by negative magnetic anomalies. Such a zone of negative magnetic anomalies stretches to Tibet and beyond. Some correspondence between the development processes of island arcs and of large mountain systems is noticed. It is assumed that the Central-Asian ridges, particularly Karakorum and Himalayas, were formed by the drift of India and Asia one toward the other, by a motion which so to speak "dropped out" the basin of the Tethys Sea ("Mediterranean" ocean).

The connection between regions and earthquake focii and fault planes on a planetary scale is considered. It is noticed that it is difficult to assume the existence of fault zones at very large depth.

In island arcs, which are zones of tremendous mobility, material transport and variations in the surface level taking place all the time, make it possible to assume variations in the depth of the M surface which are necessary to maintain isostatic equilibrium. These movements may cause the accumulation of strains and their periodical relief in the upper mantle, which in turn may cause earthquakes with very deep focii. The important difference between seismic activity in compression zones (island arcs) and extension zones (rifts) is pointed out.

The structure of the terrestrial crust on land obtained by the use of the most detailed method of seismic investigation with comparatively small explosions, is described mainly in works by Soviet authors. In most cases their research was combined with other geophysical methods mainly with gravimetry.

The most detailed research has been carried out on the Russian Platform and in some regions of Central Asia (Pomerantseva /51/, Godin, Egorkin /52/, Godin, B. Volvovsky, I. Volvovsky, Fomenko /53/) (abstracts not given). Somewhat less detailed work has been done on the territory of the Baltic Shield (Grachev, Dekhnitch, Detenyshev, Litvinenko, Nekrasova, Sosnovskaya /54/). The work has been carried out in the direction of Ukhta to Kem'. The latter investigations reliably clarified two seismic boundaries at the depth of 10—15 km with a longitudinal wave velocity of 6.6 km/sec, and at a depth of 34—38 km with the velocity of 8.1 km/sec. Less clearly determined are other intermediate surfaces of discontinuity and layers with velocities of 6.7 and 6.9—7.0 km/sec respectively. A number of non-uniformities and of deep faults, confined to contact zones of different structural-facial geological formations, are noticed.

Studies carried out in Kazakhstan (Antonenko, Popov /55/) on the Temir-Tau—Petropavlovsk route give from preliminary data a depth of 48—54 km for the M surface. The complexity of the wave picture is noted, the poor resolution and the very weak kinematic and dynamic difference between individual wave groups when there is a very large number of in-phase axes following each other in short intervals. It is interesting to note that this is apparently a local feature, since in another region of Kazakhstan, situated near Dzhezkazan, a well-resolved clear wave picture with sharp groups of depth waves was observed in previous years.

The structure of the terrestrial crust in Georgia (Balavadze, Tvaltvadze /56/) is mainly known from gravimetric data, since the amount of seismic work done there is still insufficient to provide any idea of the structural peculiarities of the terrestrial crust. The thickening of the terrestrial crust under the Main Caucasian ridge (maximum crust thickness about 60 km) and a rise in the M boundary under the Dzirul'skii massif was ascertained from a combination of data.

In a number of works some regularities in the structure of the terrestrial crust are indicated. In particular, the assumption that many mountain structures have "roots" is confirmed. Regions with different geological-development histories have different crust structures. There is an increase in the thickness of the granite layer corresponding to regions of the alpine folding, and similarly with the basalt layer, in regions of Hercynian folding. In order to determine a more complete and reliable correspondence of the structural peculiarities of the terrestrial core for a number of structures of different ages, the accumulation of as much data as possible, corresponding to regions with different geological-development histories, is necessary.

3. Geological Interpretation of Geophysical Results

In Fedynskii's work /57/ the relation between the depth structure of the terrestrial crust and the geological structure of its upper part is shown in the example of the regional work carried out in the southeast of the USSR. Zones of large gravitational gradients and of intensive regional magnetic anomalies are situated at the junction of large tectonic elements with different structures of the earth's crust. These zones mark the boundaries of blocks of the crust, which differ in internal structure and history of geological development and correspond to deep faults, and with which magmatic intrusions may have coincided.

The most mobile parts of the earth's crust are connected with the development of a granite layer and are characterized by large gravitational anomalies of deep origin. Stable parts of the crust have a less developed granitic layer and positive gravitational anomalies. The observed peculiarities are conducive to the hypothesis of a phase transformation of the subcrustal material (radiogenic heating). It is assumed that the leading deep process consists of differentiation of the material according to density, which causes vertical oscillatory motion and accompanying horizontal displacement. The combination of these dynamical factors, together with the tending of the masses of the terrestrial crust and mantle to isostatic equilibrium, forms the mechanism of tectogenesis.

Interesting considerations with regard to the structure of the earth's crust and the processes connected with its features are given in the work of Vening and Meinesz /58/. This work gives results of geophysical investigations on land and sea near New Guinea. It is shown that in the high-mountain ridges of the island there is practically no folding. It is assumed that the ridges result from the displacement to the north of a huge block of terrestrial crust along the surface of a gigantic thrust. The forces which acted on the northern block apparently were at an angle of 25—30° to the axis of the ridge. Earlier, the formation of the mountain ridge of New Guinea was related to the influence of subcrustal currents and to their movement from under the Australian continent in a northerly direction. The new data can agree only with subcrustal currents originating under Asia and directed towards Australia. The author considers that the new data indicate the effect of stretching, approximately at right angles to the western coast of Australia. As a result, a fault of the marginal graben type, whose edge of the graben sank under the ocean and coincides with the western edge of the negative anomaly belt.

The problem of the existence in the crust of intermediate dividing boundaries, in particular of the most widespread Konrad (K) boundary — the boundary between the so-called granite and basalt layers — is controversial till the present time. Also unclear is the question of the physical nature of these boundaries, as well as of the M surface, which arbitratily separate the crust from the rocks of the upper mantle or shell of the earth. However, to most investigators (Båth /59/) it is already clear that the internal structure of the crust strongly differs in different regions. In some regions the K boundary may be sharp. In others, it may be a transition region with a gradual variation in the properties. The different points of view were also determined by the fact that the works have been carried out in essentially different regions and often by different methods; sometimes even identical results were interpreted differently.

The problem of the M boundary is also far from clear (Kuno Khisasi /60/). There is an assumption that the M boundary separates the crustal rocks from the mantle rocks, i. e., that a real difference exists between layers lying above and below the M boundary. Other scientists assume that the M boundary separates layers of the same chemical composition but differing in their crystalline structure. An opinion exists that a phase transition takes place on the M boundary due to the simultaneous effect of temperature and pressure variation (Wetherill /61/). Objections to this are based on the fact that the temperature distribution in the earth, the variation of heat transfer with pressure, and a comparison of the variation in the depth of the M boundary with the variation of the heat flux, contradict the assumption that the physical state changes on the M boundary (Bullard, Griggs /62/). Connected with the problem of the nature of the boundaries of the earth's crust is the problem of the composition of the main layers constituting the crust. It is known that the terms "granite" and "basalt" layers are arbitrary. This arbitrariness is due to the fact that the propagation velocities of elastic waves in these layers are close to the velocities in persilic rocks (of the granite type) and in basic rocks (of the basalt type) under an isotropic pressure close to that which may exist in the crust at corresponding depth. Many scientists draw attention to the fact that the composition both of the granite and of the basalt layer is by no means determined by their designation (Bott /64/). However, in a number of cases, geologists accord these terms the literal meaning and draw on this basis very far-reaching conclusions. Attention to this is drawn in Rezanov's work /63/. An assumption exists that the granite and basalt layers are made of metamorphic rocks (Rezanov /65/). In a number of cases conclusions are drawn which, apparently, are not yet adequately based on fact. In particular, in /65/ a conclusion is drawn that the basalt layer, discovered by seismic investigation, consists of metamorphic rocks of Archean age.

An even less well-founded remark, which is made in Afanassiev's work /66/, is that it is necessary to take into account the influence of the pressure of the water column in the ocean on the increasing velocity in the rocks under the bottom as compared with the velocities in the continental rocks at the same depths.

4. On the International Project of Investigation of the Earth's Crust and Upper Mantle ("Upper Mantle" Project) (Schäffner /67/)

The third meeting of the International Committee on Geophysics (Paris, January 1961), adopted the proposal of the president of MGGS, V. V. Belousov, to work out the "Upper Mantle" project. In this project, a number of international scientific unions would participate. The aim of the project is the participation of scientists of the whole world in work concerned with the investigation of the upper layer of the earth up to a depth of 1000 km. For this purpose, it is necessary to carry out investigations of the variations in the physical and chemical properties of the crust and of the upper mantle in various directions and for essentially different tectonic zones. It is necessary to have data on current and earlier movements of the mantle's material, as well as on the energy sources contained there.

In seismically active zones, it is necessary to investigate the seismicity and the mechanism of focii formation, and to study the accumulation of strains by means of remote electronic devices. It is necessary also to carry out a detailed investigation of the structure of Antarctica's crust and of the isostatic influence of the ice cover, as well as to study further horizontal displacements in various regions and find new criteria for the determination of displacements along large dislocations in the geological epoch.

It is also necessary to develop and use the following geophysical investigation methods: magnetotelluric variations, study of long-period waves of free oscillations of the earth, seismic methods of study of the sedimentary layer and of deep dividing boundaries under the continents and under the ocean bed, deep drilling, variation in heat fluxes, paleomagnetic methods, methods of gravimetry and electromagnetometry. It is necessary to carry out investigations to describe the development of tectonic and magmatic processes on various continents at various development stages of the earth; to determine the geological history of various regions from a determination of the age of rocks and from the stratigraphy; to determine the role of isostasy in the development of the crust and the influence of individual layers on isostatic adjustment.

The combination of all these possible investigation methods should be intelligently used for the study of the structure of the earth's crust and upper mantle and the following individual tectonic elements. The following should be studied on continents: a) shields and stable zones; b) folded and active zones; c) peripheries of continents; d) internal and marginal seas. The following should be studied in the ocean: a) deep oceanic basins; b) submerged ridges; c) island arcs and deep-sea troughs.

Of particular interest is the investigation of seismic stratification of shields and of stable zones; the three-dimensional problem of batholiths; the study of the character of the transition from stable zones and shields to folded regions and regions of tectonic activation; the determination of the character of the variation in the structure of the crust in passing from a continent to an ocean in transition zones of different types; investigation of the continuation on the continents of submerged oceanic ridges, as well as the problem of the connection between the Indian Ocean and islands and the Atlantic ridge, and the problem whether the Lomonosov Ridge is a continuation of the Atlantic Ridge; the study of oceanic-margins for the purpose of estimating the magnitudes of current movements in these regions; the study of the character of shifts in the region of island arcs. It is necessary to establish whether any difference exists between the depth structure of various types of island arcs.

A number of works set forth the main problems that have not as yet been clearly solved or on which the opinions of scientist differ sharply. Some of these problems are of fundamental importance.

Magnitskii' /68/ considers the problem of the possible composition of the crust and in connection with it assesses whether some of the existing hypotheses on the trend of development of the crust are correct or not. It is pointed out that available geophysical data make it possible to assume an eclogitic composition of the shell. It is possible that the upper layer of the mantle consists of peridotites. The material constituting the earth's crust may form by fusion of the mantle's material, or basalt, giving upon subsequent development granite (if the mantle consists of peridotite), or from andesite (in the case of an eclogitic structure of the mantle). Andesite subsequently may differentiate into granite and basalt. If the upper mantle consists mainly of peridotite, then upon its differentiation, a basalt crust forms. When the differentiation process involves large depths, a lighter, acidic persilic material ascends, which, combining with the light melted material of the upper part, forms lavas of andesitic or granitic composition.

Two contradicting hypotheses seem to be most noteworthy: 1) initial separation of the continental crust over the whole surface of the earth and its subsequent destruction in the territory of the oceans (oceanization of the crust); 2) gradual growth of the continental crust due to progressive differentiation of the shell, and transformation thereby of the oceanic into continental crust (continentization of the crust).

In a number of works the problem of the existence and possible causes of the formation of a wave guide in the upper mantle of the earth is considered. Such causes may be: 1) the high temperature gradient at some depth under which the decrease in the velocity due to the increase in the temperature is larger than the increase in the velocity due to the increase in the pressure; 2) the transition of the shell's material into an amorphous state and 3) a mainly enstatite composition of the shell, in which at 1000°C the enstatite transforms into another modification with an increase in the volume, which should lead to a decrease in the propagation velocity of seismic waves (Magnitsky, Khorosheva /69/).

In Press's work /70/, it is pointed out that the sharp decrease in wave amplitudes at distances larger than 1500 km from nuclear explosions indicates the presence of a reduced-velocity layer in the mantle. In the work of Ringwood /71/, an attempt is made to explain the presence of such a layer by a large temperature gradient. It is shown that for a homogeneous model of the upper mantle, the required temperature gradient would lead to melting, which contradicts the observations. A stratified model of the upper mantle with a layer of reduced velocity is proposed.

In the case of such a nonhomogeneous mantle structure, the geothermal gradients existing in its upper part should not lead to melting.

In Magnitskii's work /72/, it is once again emphasized that an investigation of the composition and physical properties of the material of the upper mantle and of the processes taking place in it should make it possible to solve a number of very important theoretical and practical problems, about which contradicting opinions exist. These are the problems on the origin of the terrestrial crust, on the causes and nature of vertical movements of individual blocks of the crust, magmatism and origin of useful fossils and a number of others. The necessity to solve these problems makes the geophysical task of a thorough study of the upper mantle of prime importance, and in this connection the problem of super-deep drilling becomes especially significant.

The problem of super-deep drilling is also discussed in Hess' work /73/, where it is mentioned that geologists and geophysicists, studying the solid earth make use of remote analogies in order to form an idea of what the planet we are living on consists of. Assuming that meteorites constitute fragments of c celestial bodies similar to the earth, a conclusion is drawn that stone meteorites are analogs of the mantle's material, and iron meteorites are analogs of the core's material. * However, instead of remote analogies which are used to form an idea about the structure of our planet it is necessary to analyze that which lies under the M surface. The study of a half-ton of samples of the mantle's material will give more for the understanding of the earth's structure than all the meteorites lying in collections.

According to the proposal of Hess and Munk (Bullard /75/), made in 1957 to the American Society, a committee on deep drilling was formed for considering the possibility of drilling up to the M surface. The project was called "Mohole." For preliminary experiments the barge CUSS 1 (Continental Union Shell and Superior Oil Company) was used. The barge carries a tower 30 m high which makes it possible to drill through an opening in the center of the barge. Three experimental holes were drilled between the Guadelupe Island and the western coast of Mexixo. The main purpose was the development of drilling methods to great depths through a large water mass. The location of the first drilling hole had a sea depth of 3760 m. The position of the ship was determined by radar and acoustic methods. The system operated well. The ship maintained position to within 60 m. A drilling method was used in which it was possible to deliver the core samples without lifting the drill pipes. There have also been drilling attempts with a turbine drill /76/. The experimental holes gave fairly abundant scientific information. It was found that basalt lies under a sedimentary layer about 180 m thick. The thickness of the sediments agrees with seismic data. The detection of basalt is also not surprising. Surprising was the fact that all the sediments were clearly of Miocene age (from preliminary investigations). It seems unlikely that the Miocene is the only period when sedimentation occurred; it is therefore assumed that other sediments are buried under the basalt layer of the Pacific Ocean. Under the sediments fresh crystalline basalt with a layer of 1 — 2 mm of glass on the surface was found. It is assumed that the basalt did not penetrate in the earlier existing sediments, but simply effused to the surface. They succeeded in penetrating 15 m into the basalt and in taking quite a few core samples. Temperature measurements in one of the holes registered a heat flux twice as great as the mean flux expected for the oceans. This is in contradiction to the hypothesis that the heat source is the process of radioactive decay of elements of the granitic layer. Since there is no granitic layer in the ocean, another suboceanic heat source has to be looked for; this may have to be convection currents in the mantle, already mentioned.

In the future, it is intended to use equipment similar to that used in the first experiments, in order to drill in a number of regions of the ocean down to depths of 300 m below the ocean floor. In addition, it is intended to drill a deep hole reaching the M surface and entering the mantle rocks. For

* A. P. Vinogradov shows in /74/ that the material of the primary mantle corresponds to the composition of stone meteorites.

very deep drilling a turbine drill with diamond bits will presumably be used. The place for drilling the hole to the M surface has not yet been determined. It is desirable that the M surface be situated as close as possible to the ocean surface, that the heat flux be not too high and the weather in the vicinity be reasonably calm.

Expected results. Holes penetrating into the rocks of the mantle may dispel many doubts. Thermal measurements will make it possible to determine the temperature distribution. If it is found that the material of the mantle corresponds by chemical composition and content of radioactive components to that of stone meteorites, it will be possible to obtain grounds for calculating the thermal history of the earth.

More reliable data will be obtained on the history of the development of the oceans. By measuring the radioactivity of sediments and rocks at different levels it will be possible to determine the relative distribution of radio-isotopes. The measurement of radioactive-decay products will make it possible to determine the age of individual layers of the terrestrial crust, and possibly of the earth itself.

For geologists, the problem of the rate of sedimentation on the bottom of the oceans is of interest, since according to available data, there are no sediments anywhere older than a definite period. In this problem many contradictions exist. In particular, the assumption is made that the age of the present oceans is not as great as hitherto assumed.

Paleontologists in turn consider that it will be possible, by studying fossil remains at great depths, to fill the gap, extending over nine-tenths of its course, in the history of the evolution of species.

Analysis of samples will be made for organic carbon content, nitrogen, amino-acids and other organic components. New indications may be obtained of life on earth in its early stages, and on the conditions prevailing when life itself emerged.

In the Soviet Union, drilling of several holes to a depth of 15—18 km on land in regions differing essentially in the structure of the crust (presumably, Karelia, Urals, Caucasus, Caspian lowland, Kuril Islands) is contemplated (Vestnik AN SSSR /77/). It is proposed to accompany the deep drilling with a wide complex of geophysical and geochemical investigations. The results of such investigation will be of tremendous importance for the study of the real composition of various types of the terrestrial crust and upper mantle, in forming an idea of the distribution of mineral wealth, and for the solution of a number of major geological problems, many of which have been mentioned in the present review.

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E. A. Koridalin,

Candidate of Physico-Mathematical Sciences

GENERAL SEISMOLOGY

The development of seismology has been determined by many factors. Severe and disastrous earthquakes, for example one in Chile (1960), at Agadir (1960), Yugoslavia (1963), and others, make it increasingly important to find means of predicting earthquakes and seeking solutions to other problems of seismic zoning. The important discoveries made by the use of seismic methods in the field of the earth's structure (structure of the terrestrial crust, mantle and core), have stimulated further development, particularly in connection with the practical need of determining the regularities in the location of the mineral resources and energy in the interior of the earth. *

Of special interest are those seismic methods which are used for detecting nuclear, and in particular, underground explosions.

The introduction of radio and electronic devices and mathematical high-speed computers has immeasurably increased the technical means of seismic investigations. New detectors, recording and processing instruments make it possible to obtain the most precise, complete and objective results.

With the accumulation of observations, it became more and more obvious that the geophysical processes and their spatial interrelationship are world-wide, and thus the strengthening of international scientific communications has a positive influence on the development of seismology

1. Scientific Relations and the Coordination of Seismic Investigations

The International Geodetic and Geophysical Union comprises 7 associations, including the Association of Seismology and Physics of the Interior of the Earth /1/. The relations of Soviet geophysicists with this union are through the Interdepartmental Geophysical Committee of the Academy of Sciences of the USSR. Once in three years a general assembly of the union is held at which scientific problems, practical ways of scientific collaboration, and problems of organization are discussed. In 1960, the regular XII General

* Information on the results of work concerned with the study of the internal structure of the earth by seismic methods is given in the paper of I. S. Berzon and P. S. Veitsman "Structure of the Crust and Upper Part of the Mantle of the Earth from Geophysical Data."

Assembly was held in Helsinki, Finland /2/. A Soviet scientist, V.V. Belousov, Corresponding Member of the Academy of Sciences of the USSR, was elected the union's president. One of the important problems discussed at the assembly concerned the project introduced by the Soviet delegation for a study of the upper mantle of the earth's crust and of the influence of the processes taking place there. This project was approved. At present in almost all the countries included in the union, programs have been worked out for the participation of the national geophysical institutions in the upper-mantle project. A major role is accorded to seismic investigators in this project.

In the periods between the general assemblies, scientific contact is mantained by means of international scientific symposiums and conferences, convened by the associations. In 1961—62, the Association of Seismology and Physics of the Interior of the Earth organized several such conferences. For the purpose of uniting the work, a committee on seismic summary was created. The association's regular meeting took place in 1961 (Kondorskaya /3/). In 1962 two conferences were held in Paris to select a place for the International Center for Processing Seismic Observations and for studying the terrestrial crust.

The European Seismic Commission of the Association of Seismology and Physics of the Interior of the Earth holds regular meetings. In 1959 the meeting was held in Spain. Two scientific symposiums took place, one on the study of the seismicity of Europe and the other on surface seismic waves /4/. In 1962 the meeting was held in the German Democratic Republic /5/.

In the Soviet Union, seismic investigations are carried out at the institutions of the Academy of Sciences of the USSR and at the scientific academies of the Union republics, as well as in the Moscow and Leningrad Universities. Observations of earthquakes are conducted at 91 permanently operating stations and on a number of expeditions. The work of the seismologists is coordinated by the Council of Seismology of the Academy of Sciences of the USSR. Sessions of the Council are held regularly for discussing results of scientific work in particular directions and further investigation. In 1961 two sessions were held. One of them was devoted to problems of seismic microzoning (Soloev'ev /6/). At the second session problems of engineering seismology were discussed (Arkhangel'skaya /7/). The 1962 May session was devoted to the centennial of the birth of one of the founders of seismology, Academician B. B. Golitsyn. The session discussed problems of the internal structure of the earth (Arkhangel'skaya /8/). In October, the Council's session in Dushanbe (Tadzhik SSR) dealt with a wide range of scientific problems: the seismic regime, the spectra and dynamic characteristics of seismic waves and others /9/. In March 1963 the session was devoted to the memory of a prominent seismologist, Academician G. A. Gamburtsev.

The basic data of seismic observations are reported in bulletins issued directly by the seismic stations or by the national seismic services. In the Soviet Union, in addition to the publications of several seismic stations and scientific institutions of republics, the Institute of Physics oi the earth im. O. Yu. Shmidt of the Academy of Sciences of the USSR issues an "Operational Seismic Bulletin" every ten days, and a "Seismic Bulletin of the Network of Seismic Stations of the USSR" every month. International Seismic Summaries are also prepared and issued in Strasbourg (France) and Edinburgh (Scotland).

2. Instruments and Equipment of Seismic Stations

The development of networks of seismic stations and their increasing use of sensitive instruments make it possible to obtain more and more information on the seismic phenomena taking place. This contributes to the use of statistical methods of processing and generalization of observations.

Seismic instruments are being developed in the USSR, USA, Poland, Canada, Japan and other countries in various spheres. New seismograph systems are being devised which give readings in digital form, making it possible to introduce the readings directly into a computer. Automatic and semi-automatic devices for placing instruments in inaccessible mountain areas, where the background of seismic disturbances is low, have been constructed. Existing instrument types have been improved by introducing additional devices or by replacing individual old units of the installations with better ones, and by carrying out theoretical research on designs more appropriate to this equipment.

In the USA a standard Press-Ewing long-period seismograph with a converter of seismic oscillations has been adapted for digital recording. The instrument operates on frequency modulation, and by means of additional electronic systems the readings are recorded in analog and digital forms (De Bremaecker /11/).

Another type of digital seismograph uses transistors (De Bremaecker /12/). It operates according to a fixed program, recording oscillations once per second on a punch card. The seismograph has been tested in operation. Its use improved the methods of determining phase velocities of surface waves. Digital recording is used also for recording oscillations with large periods (Smith, Phinney, Gile /13/). Equipment with a detector of the Benioff extensometer type works with an interval of 1 minute. A large amount of statistical material regarding seismic oscillations with periods from 5 minutes and more has been accumulated by using this instrument. At some seismic stations the digitizing is introduced in a systematic working process, e. g., the Chester Field Laboratory (USA) (Bogert /14/). Two instruments exist at this seismic station: short-period Benioff seismographs and long-period Shrengnezer seismographs (with an amplifier). The instrument readings are transmitted by telephone cable a distance of 45 km to the Central Laboratory and there are recorded in analog form on magnetic tape, and in digital form on a punch card. For control, the digital data from the punch cards are in some cases converted again into analog recording, which is compared with the initial data. The three-component Press-Ewing seismograph in the Seismic Laboratory of the California Technological Institute (Pasadena, California, USA) also has a digital output (Phinney, Miller /15/).

A seismic station with digital recording of microseisms has been built /16/ in California, USA. By means of this equipment the directions of propagation of microseisms and their spectra are studied.

In the design of seismographs, new principles are used for converting pendulum oscillations due to earthquakes into analog or digital recordings. Lin'kov /17/ proposed magnetron transformation of seismic into electric oscillations by modulation of an alternating type of electronic tube by the nonuniform field of a permanent magnet. One of the transformer elements (tube or magnet) is placed on the pendulum, the second—on the instrument's stand. The displacement of the tube in the nonuniform field of the magnetic system of the seismograph results in a variation in the anode current.

A seismograph based on the use of the Hall effect in semi-conductors has been developed by the Academy of Sciences of the Polish People's Republic (Nalecz, Zawicki /18, 19/). As the Hall pickup used is made of a germanium plate 12×6×0.25 mm, the maximum magnification of the instrument is approximately 100 times larger than the magnification of a similar seismograph with an electrodynamic transformer. An important advantage of the seismograph with a Hall pickup is the absence of back effect of the galvanometer on the seismograph.

An automatic seismic station for recording weak earthquakes and explosions has been developed by Aksenovich and Serdii /20/. The recording is made on a magnetic tape. The instrument has a magnetic memory of 8 seconds. The station is automatically switched on when the level of the useful signal exceeds the disturbances by a factor of 3. Owing to the magnetic memory the recording of earthquakes is made without the loss of the first entries. The station can record up to 100 without reloading. Vetehinkin and Preobrazhenskii /21/ created a somewhat different variant of an automatic seismic station with magnetic recording.

In order to utilise seismograms to their greatest possible advantage, Rykov and Kolesnikov /22/ devised an instrument for transforming visible recording into electric current, from which it would be possible to impart motion from some kinematic elements of the soil particles to others. The seismogram on photographic paper is placed on the drum of the unfolding mechanism and is "searched" by a photoelectronic device. The interrogation frequency reaches 4000 c. p. s. The result is given in the form of pulses of the corresponding amplitude, determining the electric voltage on the instrument's output, whose form is similar to the recording on the seismogram. Kolesnikov /23/ developed a new type of recording and re-recording of photo-optical seismograms by the method of alternating width.

In order to use the most favorable conditions for mounting the seismographs, the latter are lowered to the sea bottom. Equipment for this purpose, developed by Monakhov /24/, consists of a vertical seismograph, recording apparatus and auxiliary equipment placed in a metallic sphere, which is lowered by a cable at specific locations from a ship. Bottom seismographs of this type in various modified forms have also been built in the USA (J. Ewing, M. Ewing, /25/). In one case, the seismic receivers (short-period geophones with a proper oscillation period of about 0.5 seconds) are lowered to the sea bottom together with the recording oscillograph. In another case only geophones are placed on the bottom, and the recording is made on the ship

Instrumental methods of studying strong soil oscillations during earthquakes are being improved. Kirnos and Solov'ev /26/ built a seismograph with optical recording of soil movements during earthquakes with an intensity of 6 and more. Depending on the given set of parameters the pendulum is used in accelerometer conditions ($T \approx 0.045$ sec; $D = 0.7-0.8$; sensitivity $1.6 \cdot 10^{-3}$), velocity meter ($T = 0.4-0.5$ sec; $D = 7-8$; sensitivity $1.6 \cdot 10^{-1}$) or seismometer ($T = 3$ sec; $D = 0.4$; magnification 1.5). The recording drum with the photographic paper continuously rotates at a velocity of 5 m/sec. In the idle state the illuminator lamp does not work, but a sensitive seismoscope switches it on at the time of an earthquake. When the seismoscope is in operation, an accelerated heating of the lamp's filament takes place, by a system of relay and reservoir condensors, and normal recording of the earthquake begins with a delay of only 0.0003 sec. Similar in design is a second seismograph type (E Shi-yuan', Kirnos, Solov'ev /27/). A piezo-electric accelerometer for strong movements has also been constructed (Fremd, /28/).

A simple instrument for recording strong movements has been built by the Administration of the Coastal and Geodetic Service of the USA (Cloud, Hudson /29/). The instrument consists of a conical pendulum with an oscillation period of 0.75 sec and a damping of 10% of the critical. The instrument is used for studying vibrations of buildings during strong earthquakes. In the Soviet Union, a similar type of seismoscope, but with a period of 0.25 sec, was built earlier, in 1953, by Medvedev. An electrodynamic seismograph for recording large soil displacements in the near zone of explosions has also been developed (Rulev, Kharin/30/).

Much attention has been given to the improvement and use of instruments for recording long and super-long surface seismic waves. At many seismic stations, particularly in the USA, these instruments are included in the standard equipment of a standard seismic station. In the Institute of the Physics of the Earth a long-period seismograph is mounted at the seismic station "Simferopol". A modernized SVK seismograph with a proper oscillation period $T_0=30$ sec, is connected to a galvanometer, which has a period of 80 — 130 sec, depending on the adjustment. At the time of the Chilean earthquake of 1960, the seismograph recorded surface waves with periods up to 480 sec (Arkhangel'skii, Kirnov, Popov, Solov'ev /31/).

In Freiberg (German Democratic Republic) a rod deformograph is mounted. A quartz rod 25 m long is fixed at one end in the bedrock and the other is connected to an inductive pickup. The deformograph can record long-period seismic waves, deformation of the terrestrial surface and its slopes (Hiersemann /32/). Similar deformographs exist in the USA and in Japan. In the USSR such instruments are mounted in Kazakhstan and in Georgia. Specialized seismic instruments for studying specific seismic phenomena are being built.

High-speed seismic equipment for informing on tsunami has been put into operation in the Soviet Union. Kirnos and Rykov /33/ developed two types of equipment one for determining the epicenters of catastrophic earthquakes and the other for determining the epicenters of medium-intensity earthquakes. Each device includes two instruments, one of which determines the direction of the epicenter, and the second — the epicentral distance and earthquake intensity. The total magnification of the first device is 25, and of the second 500. For observations in holes Walfe /34/ created a high-sensitivity seismograph recording the pressure. A number of authors carried out investigations on the improvement of the theory and technique of determining instrument constants and their frequency characteristics, as well as on the building of additional and auxiliary devices for improving the operation of existing seismograph systems /35 — 52/.

New recording instruments have been proposed and are being used. In some oscillographs of the new type the recording is done electrographically. In the oscillograph built by Borisevich and Zhilevich /53/ the recording is made by a light ray which is reflected from mirror galvanometers onto a paper tape with a semi-conducting film. The instrument has an elctrostatic memory. Broding /54/ developed an electronographic oscillograph, in which a slow time variation in the observed signal is traced as a clear curve. For recording seismic processes a luminescent method is used (Borisevich, Gol'dfarb /55/).

To obtain uniform and comparable observations, identical, standard seismic equipment should be used by seismic stations. At the present time, a number of standard instruments are being used in the Soviet Union (Arkhangel'skii, Kirnos /56/). For recording seismic oscillations during strong earthquakes use is made of the CMR-2 instrument—a two component horizontal seismograph with a mechanical recording of earthquakes of intensities of 3—7. The three-component SRZO-1 seismograph, with optical recording, is used for recording accelerations, velocities of displacements of the soil during earthquakes of intensities from 6 up. A simplified modification of this instrument (UAR) is used for mass observation. The SBM and AIS-2 seismometers estimate the intensity of earthquakes from maximum deflections. The recording of distant and weak local earthquakes is made by SK-3 instruments (magnification $1 \cdot 10^3$ for wave periods of 0.5—10 sec); by high-sensitivity SKM-3 seismographs (magnification $1 \cdot 10^5$ in the wave period range of 0.3—1.5 sec); and by USF seismographs with approximately the same parameters. For recording earthquakes that are near use is made also of the VEGIK and SKh instruments. The magnification of these instruments in the wave period range of 0.1—0.6 sec reaches $2 \cdot 10^4 - 5 \cdot 10^4$. Modified SK-3 seismographs are used at some stations for recording long-period surface waves (over 15 sec).

In the USA and in other countries, where the Coastal and Geodetic Service of the USA organizes seismic stations (according to the VELA-UNIFORM project there are altogether 125 stations), the standard equipment consists of two basic types (Murphy /57/). One is the short-period Benioff seismograph with a maximum magnification of about $1 \cdot 10^5$ (for periods of 1 sec), intended for recording body waves of distant and weak local earthquakes, as well as for recording seismic oscillations from nuclear explosions. The other is the seismograph of the Shrengnezer or Press-Ewing system which is intended for recording long-period surface seismic waves (up to 100 sec). In the USA, in addition to standard stations, seismic stations have been built with the basic task of recording nuclear explosions, in particular underground explosions. One of these stations is organized in the Wichita Mountains 25 km to the northwest of Lawton, Oklahoma (Gudzin, Hamilton /58/). Two horizontal Banioff seismographs are standard equipment. The vertical component is recorded by a group of 10 seismographs giving a magnification of up to 3×10^6 for periods of 0.3 sec. In addition, the station has a 3-component mounting with a narrowed transmission band and with a maximum magnification of 5×10^4 for periods of $\approx$ 1 sec. There is also a three-component mounting of seismographs with a wide-band characteristic and with a magnification of $\approx 2 \times 10^3$ for seismic waves with periods from 0.1 to 10 sec; as well as a 3-component mounting of long-period seismographs for recording surface waves with a magnification of 2×10^4. The recording, after the magnification of the useful signals, is made at a central point by a multi-channel oscillograph on a 16-millimeter cine film. Efforts are being made to find even more convenient places for setting up such stations in order that the equipment may have a higher effective sensitivity than mentioned above (Murphy /59/).

3. Physics of Earthquakes

In this section, seismic regime, seismic waves and tsunami, the mechanism of focii of earthquakes, some methods of interpretation and the processing of observations will be considered.

Seismic regime. The seismic regime is characterized by the positions of the foci and by the energy parameters of the earthquakes by their space and their time variations. Investigations of the regime are of fundamental importance for the development of specific trends of seismic investigations, e.g., forecasting of earthquakes, seismic zoning, genetic relations between earthquakes and tectonic processes.

The most systematic research on the seismic regime concept was carried out by Riznichenko and Nersessov in the Complex Seismic Expedition of the Institute of Physics of the Earth im. O. Yu. Shmidt of the Academy of Sciences of the USSR during its work in Tadzhikistan. (Riznichenko, Nersessov /60/). Quantitative parameters were introduced in order to describe the seismic regime. The frequency of earthquakes $N = N(E)$, where is the earthquake energy, were investigated. The frequency was referred to a chosen area and to a time unit. The energy is characterized by its flux, which passes through the surface of a sphere with a radius of 10 km, in the center of which the earthquake focus is situated. A classification of earthquakes according to energy, the criterion of which is the quantity $K = \lg E$. is introduced. The quantity $T_i = 1/N_i$, the reciprocal of the frequency, expresses the mean time interval in chosen units between earthquakes of the class $K=i$. The graph of the frequency plotted with a system of coordinates $\lg N$, $\lg E$, represents a segment of a straight line characterized by the slope γ. The quantity A_i is the seismic activity and determines the numerical value of the frequency of earthquakes of the class $K=i$. The variation in the quantity in time is investigated. Theories and methods of plotting seismic activity maps and maps of probable earthquakes are developed.

Some scientists studied the seismic zone and individual earthquakes of the Vrancei Mountains (Rumania). This zone is situated in a fold of the Carpathians, where their trend varies sharply from latitudinal to meridional. The focal zone of earthquakes is distinguished by the fact that it lies at a depth depth of 100—150 km. This is one of the few and most clearly pronounced regions of Europe with intermediate earthquake foci. Particularly strong earthquakes occured in 1838 and 1940, the tremors reaching large distances from the epicenters (over 1000 km). As a result, in the 1940 earthquake, vibrations were felt in Moscow. The town of Kishinev was severely damaged in both earthquakes. Sagalova investigated the recording of 52 earthquakes of the Vrancei zone with M from 4 to $7^1/_2$. An approximate estimate was made of the frequency of earthquakes (Sagalova /61/). Works of the Rumanian seismologists Iosif and Radu /62/ are devoted to the study of the seismic regime of this region. They published data on the magnitudes of 250 deep earthquakes during 1937—1958 (with $M \approx 2.7—7.4$). It was found that the seismicity of the Vrancei Mountains increased in the 19th century. The research of a number of authors /63, 64, 66/ is devoted to earthquakes of this region.

When the frequency of earthquakes in Bulgaria was studied (Khristovskov /66/), use was made of information on earthquakes with a magnitude of from 5 to 11 during the last 70 years. The following relationships were found: $N_M = N(M)$ and $N_E = N(E)$, where M is the earthquake magnitude and E is the energy.

A study of the relationship between the magnitude and number of earthquakes, as well as between the magnitude and depth of earthquake foci, was made by Japanese scientists (Ikegami /67/, Kurimoto /68/).

After sufficiently strong earthquakes a series of weak shocks — aftershocks — usually occur. Their detailed study made it possible to form an idea of the peculiarities of the focal zone, of deep faults, along which the foci of secondary earthquakes migrate, and of the mechanism of the latter, as well as of the variations and formation of the seismic regime. Pshennikov investigated repeated shocks of 6 earthquakes in the Baikal area and Mongolia with $5 < M < 7^3/_4$. It has confirmed that the higher the energy of the principal earthquake, the larger the volume of the focal zone. It has been found that earthquakes with energies of $10^{17} - 10^{19}$ ergs are usually not accompanied by repeated shocks (Pshennikov /69/). Solov'ev and Solov'eva /70/ studied extensive seismic data with the purpose of determining the relation between magnitude and fall-off in seismic activity in subsequent aftershocks. It was established that the mean number of subsequent shocks with magnitude M_0, exceeding some given level M, depends only on the difference $M_0 -$ and does not depend on the abosolute value of M_0. Some correlations were determined between the magnitude of aftershocks and the depth of earthquake foci. The earthquake at the southeastern edge of Kamchatka on 4 Ncvember 1952 was accompanied by numerous subsequent shocks. Tarakanov /71/ studied 439 aftershocks. Their foci were situated in a fault zone stretching to the east and along the Kuril-Kamchatka arc. It was observed that in the course of time the earthquake foci migrated to the west. Other works are also devoted to the study of aftershocks (Khovanova /72/, Utsu /73/).

In addition to the determination of "internal" regularities in the appearance of earthquakes and their subsequent shocks, attempts are being systematically made to relate seismic phenomena, and their regime to other processes accompanying the development of the earth, or to extra-terrestrial factors (Tamrazyan /74/; Sytinskii /75/; Matveev, Golubitskii /76/).

Seismic waves. The body of work concerned with the study of the characteristics, nature, regularities and peculiarites of the propagation of seismic waves, is extremely diversified and wide. It includes theoretical works on the propagation of body and surface waves in stratified media of different models of the earth, on the conditions of their reflection, refraction and attenuation; experimental data and their generalization; theoretical calculations and observations of the proper oscillations of the globe.

The works of Osipov /77/, Telezhko and Frolova /78/ and Bortfeld /79/ give the solution to the problem of the reflection and refraction of plane elastic waves on the boundary between a liquid and a solid medium. Theoretical problems of the propagation, reflectiona and refraction of waves in nonhomogeneous, anisotropic, viscous media are considered in the works of Yoshiama Ryoichi /80/ Musgrave /81/, Herlas Burgos /82/.

Work on the dynamics of seismic waves has been carried out by Leningrad Division of the Mathematical Institute im. V. A. Steklov and by the Leningrad University (Petrashen', Alekseev, Yanovskaya and others), as well as in the Institute of Physics of the Earth im. O. Yu. Shmidt of the Academy of Sciences of the USSR (Zvolinskii, Keilis-Borok and others). In particular, Alekseev /83/ critically analyzes the empirical concepts on the dominant character of head waves in multilayered media. He suggested a more general model with layers, in which a vertical velocity gradient exists instead of the now-accepted multi-layered-homogeneous model of the structure of the upper part of the earth. The work of Aver'yanov /84/, is devoted to the same problem and gives experimental data on refracted waves, due to the presence of gradient media, obtained in the northwestern part of the Sea of Okhotsk. Kogan /85, 86/ considers the effect of energy absorption on the form of a seismic pulse and on the absorption coefficients. Whereas for a monochromatic wave the absorption during its propagation is determined by a simple exponential law, a wave packet, forming a seismic pulse, has a more complicated character, since the absorption depends on the frequency. Examples are given of pulse deformation of a simple form as a result of energy absorption.

Some works are devoted to the problem of propagation of seismic waves through the central parts of the earth. Zharkov /87/ considers the reflection of seismic waves on the boundary of the shell and core. He shows that the reflection factor of SH-waves at small departure angles depends largely on the viscosity of the core. Observations of these waves near a seismic shadow make it possible to estimate the viscosity in the core. In the work of Knopoff and Freeman /88/, the diffraction of elastic waves by the earth's core is reported. The behavior of the amplitudes of a diffracted wave in the shadow zone formed by the terrestrial core is also considered.

In the analysis of seismograms, new wave groups are determined whose nature is subsequently clarified. Studying earthquakes on the northern coast of California (USA), Cameron /89/ investigated the phase of P_F' in detail. This wave is situated between P and S. It was earlier described by Byerly as a "pseudo S." The author plotted the hodograph of this wave and determined the propagation velocity, which was found to equal 5.1 km/sec. It was established that this wave belongs to the longitudinal type and propagates in the surface layers of the continents.

Analyzing recordings of bathyseisms in the Vrancei Mountains, Eneuscu /90/ and Ionescu-Andrei-Pana /91/ detected intermediate clear entries, characteristic of depth foci of individual groups of seismic waves between P and S. The nature of these waves has not yet been established.

Simulation of the propagation of longitudinal waves in the upper mantle of the earth was carried out by Riznichenko and Shamina /92/ by the ultrasonic pulse method. The following structural schemes of the mantle were considered: 1) the velocity of seismic waves in the mantle increases with depth; 2) the velocity decreases with increasing depth; 3) there exists a channel with reduced velocity. Shamina and Lebedeva /93/ studied composite waves on two-dimensional models. Khorosheva /94/ investigated a wave guide by the ultrasonic method on a solid two-dimensional model with sharp boundaries in order to clarify the propagation features of P_a waves.

The works of a number of authors /95—101/, in addition to those already mentioned, are devoted to the study of body waves, their characteristics, propagation regularities and peculiarities.

Many investigations are concerned with the study of surface waves, their theory, properties, analysis and generalization of experimental observations.

In various cases the dispersion of Rayleigh and Love waves is studied. An approximate method for calculating dispersion curves in a nonhomogeneous half space is proposed (Byath, De Vault /102/). The variational method, used for studying the dispersion of Rayleigh waves, was utilized by Kabayasi and Takeuri /103/ to determine calculations referring to Love waves. The dispersion curves of both types of surface waves are calculated by means of high-speed computers for specific conditions /104—109/. Mal /110/ theoretically investigated the influence of an increase in the thickness of the earth's crust under mountain structures from the dispersion of Love waves. It was shown that an increase in the crust's thickness leads to a decrease in the phase velocities in the short-range period. Sâto Ryôske /111/ described the dispersion peculiarities of Love waves for the case where the thickness of a homogeneous layer, lying on a homogeneous half space, varies in a step whose amplitude is small when compared with the wavelength.

Porkka /112/ investigated the dispersion of surface waves on some Eurasian paths from earthquake recordings at the seismic station in Helsinki. The dispersion curves of surface waves for earthquakes in Tibet are characterized by lower group velocities than for other earthquake regions. The author explains this by the considerable increase in the thickness of the terrestrial crust in regions of young mountain structures. Kuo, Brune and Major /113/ studied the dispersion of Rayleigh waves in the Pacific Ocean in the range of 20 to 140 sec periods. Some conclusions were reached on the structure of the terrestrial crust in specific parts of the Pacific Ocean. Shechkov and Solov'eva /114/ studied group velocities and the peculiarities of Rayleigh waves for mixed continent ocean paths. It was shown that in the western part of the Pacific Ocean the terrestrial crust is thicker than in the central part. Levshin /115/ studied experimentally explosion-generated surface waves in loose rocks. He also studied the dispersion of waves and compared the results with the structure of the sedimentary layer.

Oliver /116/ prepared a summary of observations of the dispersion of surface Rayleigh and Love seismic waves. The curves involve a wave range with periods from 1 second to 1 hour and a velocity range from 1 to 8 km/sec. Graphs are given of the phase and group velocities of the basic Rayleigh and Love waves propagating on continents and oceans.

Other works too are devoted to the study of the dispersion of Love waves /117—120/.

The spectrum of surface waves covers a large range of periods (from seconds to hours). The nature and mechanism of individual groups of these waves are different and not always clear.

Super-long (over 150 sec) surface waves appeared at the major earthquakes, including those of Assam (1950), Kamchatka (1952), Alaska (1958), and Chile (1960). The recordings of these waves were made by seismographs, quartz deformographs, and tiltmeters. Using observations in Pasadena, in Polyside and at other USA stations, as well as in other countries, Benioff, Press and Smith /121/ gave results of an analysis of the recordings of the Chilean and Kamchatka earthquakes. It is reported that both torsional modes (up to the 11th order), and spheroidal modes (up to the 38th order) of free oscillations of the earth were obtained. The main spheroidal oscillation recorded by the deformograph at the Isabel station (California) showed a separation into two periods: 54.7 and 53.1 min. The latter is regarded as a splitting of the proper frequency by rotation, a mechanical analog of the Zeeman effect in an electromagnetic system.

Pekeris, Alterman and Jarosch /122/, also discussing the results of these observations, report that they compared experimental observations with calculations of the spectrum of oscillations of the earth for several models. It was noted that a better agreement was obtained for Gutenberg's, and not for Bullen's «*B*» model of the earth. This is regarded as proof of the existence in the asthenosphere of a layer with reduced velocity. Nafe and Brune /123/ studied phase velocities of the Rayleigh waves of earthquakes in Alaska and Assam from recordings of seismic stationes situated along the arc of a great circle of the Earth (Uppsala, L'viro, Pietermaritzburg, Honolulu).

On the seismographs of the strongest earthquakes there are, among others, intensive long-period waves with SH polarization. The set of these wave groups is denoted by the symbol G in honor of Gutenberg who was the first to distinguish them. Very distinct G_4 and G_6 waves were observed in Paris by Gaulon /124/ on the recordings of Blum's tiltmeter of the 1960 Chilean earthquake. The recording at the Uppsala observatory of the earthquake in Peru (1960) observed good $G_1, \ldots, G_8$, waves, which traveled several times around the globe. From the amplitudes, it was possible to estimate the absorption coefficients of the energy of the waves in the upper mantle. G_1 and G_2 waves were preceded by oscillations of a smaller amplitude with shorter periods. The authors refer these wave groups to and transverse waves, propagating in a layer of reduced velocity with group velocities of 4.5 — 4.6 km/sec (Bath, López, /125/).

As mentioned above (Arkhangel'skii, Kirnos, Popov, Solov'ev /31/) particularly complete observations of surface waves from the Chilean earthquake were obtained in the Soviet Union at the seismic station in Simferopol.

Theoretical and computational works have been carried out for determining the composition and features of the spectrum of free oscillations of the earth (spheroidal, radial and torsional) postulating various assumptions as to its internal structure (Sato, Matumoto /126/, Takeuchi, Kabayashi /127/). Multiple rotation waves were determined (Pekeris, Alterman /128/). The principal mode of free oscillation of the internal core of the Earth was also determined (Slichter /129/). The theory was developed of attentuation of torsional and radial oscillations and the principal spheroidal oscillation for a model of a mean homogeneous earth and for the real earth, (Zharkov /130/). Investigations of this type include other works /131 — 134/.

Short-period surface waves (periods from 1 to 15 sec) were also distinguished and studied. Much attention is given to the group of waves denoted by *Lg*, *Li* and *Rg*. The group *Lg* is divided by some authors into 2 — 4 waves. The most stable of these are Lg_1 and Lg_2. The *Lg* and *Li* waves belong to the Love wave type, and *Rg* — to the Rayleigh type. One of their important features is the propagation of the waves only in terrestrial crust of the continental type. This feature is used to determine the type of crust in individual regions of the earth. The mechanism of the waves is not yet completely clear. Savarenskii /135/ concludes on a basis of comparison of observations and theoretical calculations that the Lg_1 wave is the first of second over tone / harmonic of the Love wave. Studying theoretically elastic SH waves, excited by a point source and propagating in a non-homogeneous isotropic medium, in which the velocity of transverse waves increases linearly with depth, Sâto Ryôsuke /136/ showed that these waves can be interpreted as *Lg* waves. The peculiarities of *Lg*, *Li* and *Rg* waves and their propagation were studied in Spain (Payo /137/), Japan (Sima /138/), India (Saha /139/), Canada (Brune, Dorman

/140/), Siberia (Pshennikov /141/) and in other regions (Val'dner /142/). Bath /143/ described the general results of a study of these waves, and gave a summarizing table of their propagation velocities from data of different authors. He considers that the formation of these waves is largely connected with the existence of a layer with reduced propagation velocities of seismic waves in the lithosphere. Other short-period surface and channel waves in addition to those already indicated were studied by: T, M and others (Green /144, 145/, Northrop /146/, Tadzime /147/, Northrop, Raitt /148/).

In addition to the multiform system of earthquake waves, permanent oscillations exist which are detected by seismic instruments. The most stable are microseisms, whose source are natural phenomena. The intensity of microseisms both in a given place, and at different observation points is different and has a definite behavior. The most widespread theory of the origin of microseisms is that of Longet-Higgins, according to which their appearance is due to the formation, under certain conditions, of standing sea waves, which cause variable pressure on the sea bottom. This theory, however, is not the only one. L. Leet and F. Leet /149/ assume that microseisms form as a result of the continuous compression of the terrestrial crust. The variable atmospheric pressure affects the intensity of the compression process, which is how the correlations between variations in the pressure field and microseisms are explained. Lin'kov and Tripol'skii /150/ conclude that the cause of microseisms is the effect of large transient waves (up to 3 m high) on the sea bottom when they are propagated over places where the sea depth varies sharply. Saha /139/ assumes that short-period microseisms (T_c = 1 sec) arise as a result of the variable atmospheric pressure on the sedimentary layer of the continent. Many authors related the regime of microseisms to the passage of cyclones and typhoons over definite routes and on this basis worked out a method of forecasting their motion (Bernard /151/, Monakhov /152/, Oliver /153/, Panasenko /154/). Many other works /155—163/ are devoted to the study of the characteristics of microseisms, their nature, regime and propagation peculiarities. Some propagation regularities of microseisms were studied on simulation devices (Savarensky, Rykunov /164/).

Marine waves, tsunami, are formed as a result of individual earthquakes whose focii are situated in the sea. With their formation and advance towards the coastline, they cause much damage and often fatalities as well. Tsunami occurred in the disastrous Chilean earthquake in May 1960 (Takahasi /165/). The severe consequences of the tsunami from the earthquake on 20 November 1960, in Peru, which caused the destruction of several towns, are described by Lotze /166/. Houtz /167/ describes tsunami which appeared in the region of Suva (Fiji Islands). The character of tsunami on Kyushu Island (Japan) is described by Takahasi and Hatori /168/. Ambrasseys /169/ generalized the observations of 141 tsunami in the Mediterranean Sea from 200 A.D. to 1961. It was shown that for individual regions the formation of tsunami is connected with bottom landslides. In Greece the reason for the formation of tsunami is apparently the deformation of the terrestrial crust.

Mechanism of earthquake foci. Only strong earthquakes leave traces on the surface of the earth in the form of crack systems. Seismic catastrophes (the earthquake in San Francisco in 1906 or the Gobi-Altai earthquake (Mongolia) in 1957) left systems of ruptures and faults stretching over hundreds of kilometers in the upper layers of the earth. An examination of such earthquakes gives some idea of the processes which take place in their foci. However, these cases are exceptional, most earthquakes not being associated with such phenomena; an idea about events in the focii can be obtained only by studying seismic waves. To use the latter, it is necessary to have hypothetic representations of the theoretical equivalent of earthquake foci. At present there is no agreed point of view on these assumptions. Some authors (in the USSR Keilis-Borok) assume a point focus in the investigation of the mechanism and simulate the strains in it by a dipole with a moment (Bessonova, Gotsadze, Keilis-Borok, Kirilova, Malinovskaya, Pavlova, Sorskii /170/). Others, mainly Japanese scientists (Honda et al.), assume a spatial focus, in particular a sphere, the strains of which are radial. Vvedenskaya put forward assumptions, based on the theory of dislocations, which make it possible to determine the principal axes of strains and the surfaces of faults in focal zones (Balakina, Schirokova, Vvedenskaya /171/). Other authors carried out investigations concerned with the determination of the strains in earthquake foci, and the positions of the principal rupture surfaces, using some of the viewpoints given above or modifying and supplementing them.

Balakina /172/ used Vvedenskaya's theory to study the general regularities in the direction of the principal strains in earthquake focii of the Pacific belt. He concluded that in the investigated strain field two systems of rupture surfaces can be observed. In one of them the surface is inclined under the continent or away from it and is characterized by movements in the direction of fall of the surfaces. In the second, the rupture surface intersects the main structures, has a sharp fall and is characterized by the prevalence of fault movement components. Similar investigations from the same theoretical positions regarding earthquake foci of Central Asia and the Caucasus were carried out by Shirokova /173, 174/. Vvedenskaya and Ruprekhtova determined the strains existing earthquake foci in the Vrancei Mountains. The general result is that the strains which determine the tectonic structure of this zone are the only ones from the surface to the focal zone, i.e., to depths of 100 — 150 km (Ruprechtova, Vvedenskaya /175/). The earthquake foci of the Tadzhik depression were studied by Kuchtikova /176/. She determined the mechanisms of 100 earthquakes, of which 98 agree with strains corresponding to a dipole with moment. The rupture surfaces found from seismic observations agree with visible faults on the surfaces of the earth caused by earthquakes. A study of the mechanism of the focii of three strong Turkish earthquakes led Öcal /177/ to the conclusion that in the focus of two of them the movements and the rupture planes are vertical. Similar investigations have been carried out by other authors /178 — 186/. Ben-Menahem, Toksöz M. Nafi /187/ studied the focus mechanism from spectra of long-period waves by using earlier developed theoretical premises. Press, Ben-Menahem, Toksöz M. Nafi /188/ proposed new methods of experimental study of two basic parameters of earthquake foci — the fault length and the rupture rate. The methods are based on the study of the free oscillations of the earth and of long-period Love and Rayleigh waves propagating in the mantle. Other works are also devoted to this problem (Aki /189/, Janovskaja, Keylis-Borok /190/). In view of the ambiguity in the theoretical premises, it would be very important to ascertain the greatest agreement with the real conditions of the processes taking place in earthquake foci. Such work is being done at the present time. Pfluke and Howell /191/ studied, by means of models, the first arrival of seismic waves caused by faults; Lavin and Howell /192/ studied the influence of separation boundaries situated near an earthquake focus on the formation and propagation of the transverse seismic waves. A model study of the propagation of seismic energy around sources of different types was made by Howell and others /193, 194/.

Orowan /195/ thoroughly considered the problem of the mechanism of seismic rupture. Byerly /196/ analyzes the causes of earthquakes: migration of foci, elastic sliding down (according to Reidu), and relative movement of continental and oceanic parts of the terrestrial crust.

Bateman and Willard /197/ report more precisely determined data on the magnitudes of vertical and horizontal displacements at the time of one of the strongest earthquakes in the USA, in 1872.

In order to study the peculiarities of the focal zone, Nersesov and Kondratenko /198/ made determinations of the velocities of longitudinal and transverse waves in the region of the Khait earthquake (Tadzhik SSR). The investigations gave anomalous velocities for body seismic waves before perceptible shocks. This work is of great importance, suggesting promising ways of determining real forecasting criteria of earthquakes, the dimensions of their focal zones and their energy characteristics.

Some methods of interpreting and processing observations. Processing of data for obtaining information on the parameters and characteristics of earthquakes is carried out in many cases, more and more often, by means of high-speed electronic computers. The coordinates of the earthquakes are determined. Bolt /199/ reports on one of these programs. The standard error in the determination of epicenter coordinates is about ± 0.05°. Computation examples are given in the work. Another example of observation processing by computers is given in his second work, which deals with propagation times of seismic waves (Bolt /200/). A program for more accurate determination of hodographs of seismic waves is also described. The results of some determinations are reported. As shown by practice, the computer time is small. Aki Keiiti, Nordquist, /201, 202/ used computer methods for calculating theoretical seismograms. High-speed electronic computers are being used more and more for processing large amounts of observations for the solution of diverse problems in the Soviet Union, USA, Japan, England and other countries. The use of computational methods greatly changes the process of accumulation and use of seismic observations in their completeness, reliability, accuracy and rapid issue of results.

Work on improving the methodical bases of the determination of the parameters and characteristics of earthquakes is being systematically continued, and new scales, instructions, graphs, nomograms etc. are being produced as a result.

A group of Soviet and Czechoslovakian seismologists developed a new standard scale for determining earthquake magnitudes (Vanek et al. /203/). Pasechnik /204/ determined the dependence of the magnitude on the peculiarities of the seismic structure in the observation region. Examples of determination of these corrections in specific cases are given. Itikava /205/ derived a relationship between the magnitude of an earthquake and the range of its perceptibility. The Hungarian seismologist Bisticsany /206/ proposed to estimate the magnitude from the duration of surface waves on the seismograms. Galanopoulos /207/ reports on a method for determining the magnitudes from macroseismic observations.

On the basis of a study of 250 earthquakes, for which the intensity, magnitude and depth of the foci were determined independently, Shebalin /208/ established an empirical relationship between these quantities. This relationship makes it possible to determine one of the quantities if the remaining two are known. On the basis of a study of Caucasian earthquake data, Aivazov /209/ developed a method for determining the magnitudes of near earthquakes. Sets of master curves have been plotted which make it possible to perform the necessary calculations. The work of Belotelov and Kondorskaya /210/ is devoted to problems of energy computation.

The methodical correctness of the determination of amplitudes and periods from seismograms plays a great role. In this connection Nersesov, Rautian, Khalturin, and Riznichenlo /211/ worked out instructions for measurements on seismograms, which are based on the experience of the works of the General Seismic Expedition in Central Asia.

Herrin and Toggart /212/ set up tables for passing from the geographical to the seismic latitude. As is known, Bullen defined the seismic latitude as $\Theta = 1.1\ \Theta_1 - 0.1\ \Theta_2$, where Θ_1 is the geocentric, and Θ_2 is the geographic latitude. The use of the seismic latitude increases the accuracy of calculations of distances along a great circle and simplifies the corrections for the ellipticity of the earth for seismic hodographs.

For a more precise determination of the position of the epicenter and of the structure of the earth's crust, new hodographs have been plotted from observations of seismic waves, and existing ones have been improved /213—217/.

4. Seismicity of Individual Regions of the Earth and Some Strong Earthquakes

The generalization of primary seismic observations in the form of catalogs and maps of epicenter positions constitutes the necessary basis for many sections of seismology and geology.

In 1961—1962 there appeared the "Atlas of Earthquakes in the USSR", issued by the Soviet of Seismology of the Academy of Sciences of the USSR, and the monograph "Earthquakes in the USSR". They contain results of more than 40 years of seismic observations in our country. In preparing the atlas and the monograph, all available data on earthquakes were critically examined from common scientific points of view. The coordinates of more than 10,000 earthquakes were redetermined. For describing earthquakes use was made of the current concepts on seismic energy. All earthquakes were classified according to energy criteria, depth of foci. and the precision of the determination of the epicenters. The work was carried out by scientific collaborators of the Academy of Sciences of the USSR and of the Academies of Sciences of the Union republics under the direction of Professor E. F. Savarenskii. The atlas contains 20 maps of epicenter positions in individual seismo-active regions and in local zones, as well as an explanatory note to the maps and data on studied earthquakes.

The monograph consists of two parts. In the first part, methodical problems are described, development of instrumental methods, methods of interpretation of observations, energy concepts and conduct of investigations on expedition. The second part describes the regional seismicity of West Ukraine, Crimea, Caucasus, Central Asia, the Baikal area, Kamchatka, the Far East, the Arctic and their individual zones. Instead of the earlier existing maps and descriptions, which differed in technique, minuteness and accuracy and which were prepared by different authors, the data on earthquakes which occurred on the territory of the Soviet Union were now processed according to a common program and generalized uniformly for all the seismic regions /218/. Work on the detailed study of seismicity and the elements of the seismic regime continues. Some additional results were published for the regions of the Kuril Islands, North Tien-Shan, Altai, Moldavian SSR, Turkmenian SSR, the Far East, and also Antarctica, where Soviet seismic stations are situated /219—225/.

Here are some examples of the study of seismicity in other countries.

The European Seismic Commission (ESC) of the Association of Seismology and Physics of the Interior of the Earth decided to prepare a seismicity map and a seismotectonic map of Europe. The first map was prepared by Karnik (Czechoslovakia), the second under the direction of V. V. Belousov (Soviet Union). At the meeting of the ESC held in the autumn of 1962 in the German Democratic Republic, the first variants of these maps were discussed and approved. The maps will be discussed in final form in the ECS in 1964 in Budapest. On the basis of this work, Karnik /226/ formulated the basic problems of further investigation of the seismicity of Europe.

From instrumental data for the period 1908—1960, Petresku and Radu /227/ determined the position of foci, magnitudes and intensities of 128 earthquakes on the territory of the Rumanian People's Republic. Some earthquakes with an intensity up to 7, whose epicenters are situated in Bulgaria or Yugoslavia, are also felt in Rumania. This work is largely supplemented by other investigations of Rumanian scientists (Gavat /228/, Saulea /229/, Iosif /230/).

Petkov /231/ and Kirov, Grigorova and Ilev /232/ report data on seismic activity in the territory of the Bulgarian People's Republic on the basis of macroseismic observations collected since 1892. A map of epicenters was plotted and a brief description of strong earthquakes given. During the past 68 years, altogether 350 earthquakes occurred of intensity not less than 4; 14 of them were strong and disastrous. The strongest were the earthquakes of 4 April 1904 and 18 April 1928. A detailed study of individual seismo-active zones on the Tunozha and Struma Rivers was carried out /233, 234/.

The seismicity of Japan is described by Hirono Takuzo /235/. He reports that the annual average is 1497 perceptible earhquakes. Forty earthquakes with $M > 5^3/_4$ have been registered during the last 30 years. Since the foci of many earthquakes are situated under the ocean bottom, tsunami arise which sometimes cause much more damage than the earthquakes. A tsunami service is organized in Japan to give informarion of their possible effects.

Rustanovich, Masaitis, and Chan Khen Suk /236/ studied the historical literature and instrumental data on earthquakes on the Korean Peninsula and generalized them, as well as considering problems of seismotectonic and relative seismicity of individual regions.

Rothé /237/ gives a summary of the investigations during the International Geophysical Year and during the International Cooperation Year. During these two years altogether 65,061 earthquakes were studied. Data are reported on their distribution over individual regions of the Earth. A list of strong destructive earthquakes is also given.

One of the strongest seismic catastrophes during the last 4 years was the Chilean earthquake of 1960. Rothé /238/ reports that the first earthquake occurred on 21 May, and that its magnitude was $7^1/_4$. The epicenter was situated on the Arauco Island to the southwest of the town of Concepcion. Until 22 June, over 200 additional earthquakes occurred on the coast of Chile. Some towns, including Concepcion and Valdivia, were destroyed. On 22 May, the earthquake was associated with tsunami which attained heights of 15 m and which extended over more than 800 km of coast length. As indicated by Khireno Takudzo /239/, the earthquakes caused shifts and faults on the surface of the earth with an amplitude of up to 2 m. Jordan /240/ specifies more accurately that of all the series of Chilean earthquakes, the strongest were the two earthquakes on 22 May (magnitude 8). During the next year 20 earthquakes with $M \geqslant 7$ occurred. More than 2000 persons perished. The total damage exceeded 500 million dollars. Takahasi /241/ describes in detail the tsunami which arose at the time of the earthquake on 22 May. Gajardo and Lomniz /242/ consider the seismicity of Chile and distinguish regions of different seismic activity. In the course of their work they collected data on more than 15 thousand earthquakes.

On 19 August 1961, a strong earthquake with $M>7$, occurred in Japan, associated with the formation of fissures in the ground, rock falls in the mountains, and sink holes. The focus depth was apparently small, since the pleistoseist region had a diameter of only about 20 km. Some of the buildings in this zone were destroyed /243—246/.

In Kamchatka strong earthquakes occurred in May and June 1959, the first with a magnitude of $7^3/_4$, the second with a magnitude of $6^1/_4$–7. The May earthquake with focus in the ocean, at a distance of about 170 km from the coast, was one of the strongest earthquakes in Kamchatka. The epicenter of the second earthquake was in the region of the Zhupanovo settlement. It was accompanied by the formation of systems of cracks, subsidences and landslides. By 1 July more than 100 shocks had been recorded. Many buildings in Zhupanovo were destroyed /247—249/.

Smith's work /250/ gives a list of 338 earthquakes in East Canada during the period 1534—1927, with coordinates, intensities, data on pleistoseist regions and individual descriptions. Ming Tung Hsu /251/ reports data on earthquakes on Taiwan Island and gives a description and a map of the isoseismal lines of the destructive earthquake of 1935.

Earthquakes are also studied from the point of view of the geological conditions and premises of their manifestation and results. Rudich /252/ investigated the relation between deep-focus earthquakes on the eastern margin of the Asian continent and large structures of the terrestrial crust. It is shown that the deepest-focus earthquakes (400—500 km) correspond to the oldest structures. Gzovskii, Gorshkov and Shenkareva /253/ compared the seismicity of Hungary with its tectonics. Gzovskii /254/ considers the geological criteria and main parameters of tectonophysics and their relation to seismicity on the basis of the history and mechanism of tectonophysical movements. Gubin /255/ arrived at the conclusion that shocks are the result of ruptures in geological structures of different types and dimensions. The author relates the intensity and frequency to the dimensions, geological structure and other characteristic criteria. Rey Pastor Alfonso /256/ studied seismic data of mountain regions of East Spain. A description of the geological structure of the region, a tectonic map and a catalog of earthquakes is given.

Miyamura /257/ analyzes the geographical distribution of seismic zones and of the strongest deep-focus earthquakes. He considers the totality of earthquakes in Japan and proposes a variant of its seismotectonic map. The general scheme of geotectonic cycles and periods of seismic activity is discussed.

5. Applied Seismology

Of the many problems in this section, seismic zoning, engineering seismology and seismic investigation of explosions are considered.

Seismic zoning. Division of seismo-active territories into regions of different seismicities, expressed in the earthquake intensity scale of 12, has been adopted in the Soviet Union. To determine the seismicity, use is made of the whole set of seismostatistical and tectonic data. Petrushevskii /258/ stresses the fact that seismic zoning should be considered as a complex geological-geophysical problem. In seismic investigations much attention should be given to the historical-structural analysis, taking into account the seismo-statistical material. Medvedev /259, 260/ points out that the determination of the maximum intensity of expected earthquakes, within outlined zones, should be based on the intensities of the strongest past earthquakes, taking into account geological criteria. As mentioned above, a study of the seismic regime gives objective quantitative criteria for seismic zoning. As investigation data accumulate, the delineation of the seismic regime is used for improving the seismic zoning maps. Characteristic in this respect is the work of Vvedenskaya /261/ "Generalization of Seismostatistical Data in Seismozoning of Central Asia."

When doing any work concerned with the preparation and improvement of maps of the seismic zoning of the Soviet Union, it is very important that the collection, processing and generalization of observations be carried out uniformly for different seismoactive regions. Instructions on seismic zoning have therefore been issued, constituting a methodical manual for scientific workers engaged on such work (Medvedev et al. /262/). Methodical recommendations are also contained in the work of Vvedenskaya /263/ and Bune /264/.

Eiby /265/ also considers the problem of seismic zoning. He notes that seismic zoning is carried out better in the Soviet Union than in other countries and considers that the best data are those on the frequency of earthquakes. Data on earthquakes in New Zealand are given together with some considerations regarding seismic zoning. Gorshkov reports on the seismicity, geological conditions and seismic zoning of the territory of Burma. A large quantity of geological and seismic observation material and a number of maps, including a map of seismic zoning are given by Gorshkov /266/. In a second work /267/ Gorshkov considers the problem of seismic zoning of Asian countries. He assumes that, by using maps of seismic zoning of the Soviet Union and of the Chinese People's Republic, it is possible to plot seismic zoning maps also for other countries of Asia. Seismic zoning was carried out in Rumania. Petrescu and Radu /268/ report on the working conditions and the criteria applied. A map of seismic zoning of Rumania is given. Petkov /269/ investigated the geophysical fields (gravimetric, magnetic) of the territory of Bulgaria and compared their characteristics with the peculiarites in the seismic regime. Correlations between zones of the maximum frequency of earthquakes and lines of the highest maxima of the gravimetric field intensities are indicated. A new seismic map of Mexico was plotted based on the processing of instrumental data on 18,211 earthquakes during the period from 1909 to 1956 (Figueroa /270/). A seismic map of the Salvador republic was published published /271/.

In addition to the subdivision of large territories with respect to seismic danger, there is also a need to indicate which sections within these territories are the most stable at the time of earthquakes. When trying to solve this type of problem, not only general seismotectonic conditions, but also ground peculiarities, microgeology and morphology, are taken into consideration. Several works are devoted to the technique of microzoning (Solonenko /272/, Kats /273/, Piruzyan /274/). As in general seismic zoning, in microzoning it is important to carry out the work according to common principles and from the same point of view. To achieve this, instructions have been prepared with indications regarding methods of work (Medvedev, Bune, Dzelishvili et al. /275/).

Kuliev /276/ gives results of seismic microzoning of the Apsheron Peninsula. He generalizes macroseismic and instrumental observations, data of prospecting geophysics and acoustic hardness of soils. On this basis, a microzoning map was plotted to a scale 1: 100,000. Lyamzina /277/ reports the results of the study of the seismic properties of soil for microzoning in the town Makhachkala. Antonenko /278/ describes the results of microzoning in the town Alma-Ata from observations of microseisms with periods of 0.1 — 0.3 sec. The corresponding town map was plotted.

Engineering seismology. To increase the population's safety in regions subject to earthquakes, special measures are applied in construction to increase stability.

In order to exchange experience and work out general regulations for construction in regions of seismic danger, international conferences on engineering seismology are held periodically. The last took place in Japan in 1960 (Tanabasi /279/).

The development of work in the field of engineering seismology, in particular in the Soviet Union, is described in Medvedev's book "Inzhenernaya seismologiya" (Engineering Seismology /280/).

To solve the problem of forecasting seismic effects on structures it is necessary, as pointed out by Medvedev, to develop a seismic scale, and to carry out seismic zoning and microzoning. It is proposed to determine the intensity of seismic effects by means of a standard pendulum with a fixed period $T_0 = 0.25$ cm and a logarithmic attenuation decrement $\lambda_0 = 0.50$ (Medvedev /281/).

The adoption of measures increasing earthquake-resistance of structures makes building more expensive. In this connection problems of economic expediency are discussed. Medvedev /282/ arrives at the conclusion that in regions where the seismic danger is estimated at 9, 8 or 7, it is expedient to take anti-seismic measures only in the construction of buildings expected to last respectively 40, 110 and 150 years. Derleres /283/ recommends designing structures without allowance for seismic forces, but correctly choosing the materials and the general design of the structure.

Some research is devoted to the theory and calculation of the proper vibrations of structures, to their interaction with soils and behavior during earthquakes. Sinitsin /284/ considered the general problem of the influence of a travelling seismic wave on massive structures. Tanabasi /285/ and Ando /286/ give results of calculations of nonlinear vibrations of structures. Mikulinskii and Mironov /287/ considered the problem of determining the stress tensor in structures by means of experimental data on soil vibrations which arise at the time of an earthquake or explosion. The corresponding formulas for practical calculations are given. Vergun and Whitmore /288/ give calculations of seismic effects on long-span multi-floor buildings. To perform a dynamical analysis of a 21-floor house, analog computors were used, and some calculations were made on models. Housner /289/ considers the design conditions of buildings of electric stations with nuclear reactors, taking into account the effect of seismic forces. The works /290—294/ are concerned with these problems.

Theoretical assumptions and calculations were developed for dams constructed in seismoactive regions. Ambraseys /295/ considers dams as elastic systems. Practical recommendations on their antiseismic reinforcement are given. Caloi /296/ draws attention to the possibility of using geophysical methods when determining the physical properties of areas intended for the construction of high dams. Natanaka Motohiro /297/ gives resistance calculations of gravitational-type dams during earthquakes. Minami /298/ considers general methods of seismic design of earth dams. He analyzes the conditions of plastic equilibrium taking into account elasticity. Formulas determining the stability conditions and examples in calculation are given.

Data of experimental observation, and also a simulation of the behavior of engineering structures during earthquakes, considerably enrich the experience of antiseismic construction. Blum and Binder /299/ report on the determination of the proper vibrations of a multifloor building during construction, when the distribution of masses, rigidities and other characteristics of the structure were determined. A comparison of the measured and earlier calculated vibration periods gave good results. Experimental data are also reported in other works /300—303/.

The behavior of arch dams with the passage of seismic waves through them is described by Okato and Takahasi /304/. Artificially excited dam vibrations were investigated by means of seismographs placed in the dam and in its foundation. Data on the stresses in the dam were obtained. Data on the vibrations of earth dams during earthquakes are reported by Ambraseys /305/. Oberti and Lauletta /306/ consider problems of simulation of the vibrations of engineering structures during earthquakes. The basic propositions of the theory are established. They stress the necessity to take into account the vibration spectrum. Data of experiments with models are given. Clough /307/ describes the results of a study of earthquake effects on submerged structures. The main investigations were carried out with structure models placed under the water on a vibration platform. During earthquakes, earth channels are often destroyed. As reported by Il'yasov /308/, who worked on the effects of seismic forces, models were studied on a seismic platform of programmed control.

Nazarov /309/ considers it necessary to create vibration platforms for the simulation of seismic processes, which would not only have translational motion as a whole, but which would also deform during the motion according to a preset program. The motion of such platforms, in the author's opinion, corresponds better to the motions of soil platforms during earthquakes.

The experience gained in the study of the effects of seismic vibrations on engineering structures, and the developed antiseismic measures, are generalized in a number of countries into norms or codes, having the importance of state standards in construction in seismo-active regions. Such norms in the Soviet Union are approved by the State Construction Committee of the Council of Ministers of the USSR. Norms are being worked out also in other countries /310—313/.

Seismic investigations of explosions. During recent years, seismic investigations of nuclear explosions have become of special interest in connection with the problem of their detection.

The study of the conditions of excitation of seismic waves by nuclear explosions, their characteristics and also propagation peculiarities, is carried out according to a wide program. Thus, according to the Vela project (USA) for the collection of information, 125 seismic stations are being organized, distributed according to a definite plan in various regions of the earth (in addition to the USA). Ninety scientific-research subjects, related to seismic investigation of nuclear explosions are being elaborated (Bates /314/, Romney, Bates /315/).

Wright and Carpenter /316/ made theoretical calculations of polarized transverse Love waves excited by underground explosions. As reported by the authors, observations confirm these calculations. Werth, Herbst and Springer /317/ give a comparison of theoretical seismograms with observed waves of the nuclear explosions Blank, Logan and Tamalpais, and the characteristics of longitudinal seismic waves refracted on the Mokhorovičič boundary. Theoretical and experimental data agree on the form of the recordings and the oscillation periods. Stewart and Diment /318/ give results of experimental determinations of seismic wave periods recorded from the explosions of Nevada, Smoky and Blank and from the repeated shock of an earthquake. A difference in the periods due to explosions and to earthquakes was obtained. The authors assume that this is due to the generation peculiarities of seismic waves produced by an explosion. Rocard /319/ analyzes the influence of the height and depth of explosions on the character and intensity of the seismic waves they cause. He uses measurements during nuclear and chemical explosions; some regularities have been established. Cloud /320/ reports on the spectral composition of seismic oscillations from the Blank and Logan nuclear explosions. Similar data on the parameters of seismic waves from nuclear explosions are contained in the work of Carder and Cloud /321/. Observations of many seismic stations in the USA are analyzed and results of a spectral analysis of seismograms are given. It is indicated that according to seismic data, an explosion equivalent to 19,000 tons corresponds to earthquakes of magnitude 4.8. Peet /322/ developed theoretical assumptions on the formation of seismic waves around a spherical explosion cavity on the basis of the shock wave theory. Quantitative relationships between the charge weight and the amplitude of the seismic waves are being established. A spectral function is found under some simplifying assumptions expressing the dependence of the amplitude on the oscillation frequency for a given charge. The results of experiments and their comparison with theory are described. De Noyer, Willes and Wilson /323/ report on an observed asymmetry in the propagation of seismic waves from a chemical explosion of 500 tons, from observations at stations with an epicentral distance of 190—287 km. The asymmetry is caused not by peculiarities in the geological structure on the different propagation paths, but by diffraction phenomena in the immediate region of the explosion. Also devoted to the conditions of the formation of seismic waves by explosions and their characteristics are the works of Aoki /324/, Carder and Mickey /325/, Dorman, Moor and Rolnick /326/ and others.

Some describe the disturbances in soils and in mountain massifs resulting from powerful explosions. As a result of numerous experiments in the study of the seismic effect of chemical explosions in some compact soils, Kuz'mina, Romashev, Rulev, Kharin, Shemyakin /327/ established regularities in soil motions in the zone adjacent to the explosion. The distinctive features of these motions were recorded by sign photography while the quantitative relationships were determined from seismograph recordings for large displacements. In the works of Nordyke /328/ and Violet /329/ problems of the formation of craters in nuclear explosions are considered. Hoy and Foose /330/ give a detailed description of the deformation of the terrestrial surface caused by a nuclear explosion in a salt mine.

Much attention has been given to the problem of detection of nuclear explosions and their differentiation from earthquakes. Stubbs /331/* describes the equipment of a seismic station in England intended for the detection of nuclear explosions; 22 seismographs are arranged in two perpendicular lines, 2 km one from the other in special wells. The seismograph readings are transmitted to a central point where they can be grouped and analyzed. It is indicated that 20 such stations over the whole world would provide control of nuclear explosions. Don Leet /332/ considers in detail the problem of the detection of underground explosions. He regards the presence of only a *P* wave as a basic difference in the recordings of seismic waves at a large distance from an explosion. Examples of recordings of seismic waves at the College station (Alaska) at the time of the "Gnome" explosion are given. A doubt is expressed on the possibilities of carrying out numerous explosions in large underground chambers. Keilis-Borok and Malinovskaya /333/ are concerned with the same problem. They describe a method of identifying explosions from the arrival of body waves.

In connection with problems of the detection of nuclear explosions, the conditions of their production are discussed, in particular the "decoupling" of the explosion from the soil, in order to weaken the seismic effect. Latter, Le Levier, Martinelli and McMillan /334/ propose a theory of attenuation of the intensity of seismic oscillations in the case of underground nuclear explosions in deep spherical chambers; the relationships between the absorption of energy of seismic waves and the dimensions of the chamber are investigated. In the work of Adams and Carder /335/

* See also /58/.

experimental data on the attenuation of the seismic effect of underground explosions are given, in the case of chemical charges of 225, 450 and 900 kg. It was established that in a chamber of radius 1.85 m, the decrease in the maximum amplitudes of seismic vibrations ("decoupling coefficient") is up to a factor of 30. It was found that the decoupling coefficient is independent of the epicentral distance. Results of a study of the decoupling coefficient for short epicentral distances are also reported by Murphey /336/. Willis and Wilson /337/ consider the problem of the decoupling effect on the spectra of seismic oscillations. Results of experimental measurements are given, and a number of relationships between the oscillation periods, the chamber size and the explosion power are established. Devoted to the same problems are the works of Haskell /338/, Latter, Martinelli, Mathews, McMillan /339/; Herbst, Weth and Springer /340/ and others.

Experimental investigations have been carried out to determine the seismic effect of fairly powerful industrial explosions. Medvedev and Lyamzina /341/ report results of instrumental measurements of the amplitudes and periods of seismic waves at different distances from explosions in mines. Relationships between the charge weight, the distance from the explosion and the intensity of the seismic oscillations were obtained. Methods are proposed for estimating the seismic effect of explosions in the units of the seismic scale. The work of Aoki /342/ is devoted to the same problems. Kirillov /343/ describes the basic results of investigations of the seismic effect of explosions, carried out in the Institute of Physics of the Earth im. O. Yu. Shmidt of the Academy of Sciences of the USSR during 25 years. He considers problems of the transformation of the explosion energy into seismic oscillations energy, the effect of seismic waves on structures, and the determination of seismically dangerous zones in explosions.

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E. V. Karus

Candidate of Physico-Mathematical Sciences

EXPLORATION GEOPHYSICS

(Basic results in the development of geophysical methods for the investigation of the terrestrial crust and mineral prospecting)

The future program of construction, and a further rise in the national economy of the USSR, require sharp expansion in raw-mineral production in our country. In the program of the Communist Party of the Soviet Union, adopted at the XXII Congress of the party, it was decided that all achievments of the sciences of the earth should be used for developing and improving existing methods of geological prospecting. Among them a most important role is accorded to geophysical methods (Karus /1/).

The present review summarizes investigation results in exploratory geophysics, given in "Referativnyi Zhurnal Geofizika" mainly in 1962. Individual works were used from the issues published in the journal in the first half of 1963. Results of investigations are given in the improvement of existing methods of exploratory geophysics and the development of new methods, leading to an improvement in theory, equipment, technique and interpretation, to a rise in the geological efficiency, the precision and detail of the methods, a decrease in the cost and to an increase in productivity. It was borne in mind in this connection that the development of geophysical methods in recent years led to the solution of the following problems:

1) study of the regional structure of the earth's crust for the purpose of establishing regularities in the location of deposits of various minerals by a complex of geophysical methods;
2) prospecting and preparation for deep drilling of oil-gas structures;
3) prospecting for various ore deposits;
4) application of geophysical methods to the solution of problems of hydrogeological and engineering geology problems (Godin, Polshkov, Ryabinkin, Fedynskii, Fotiadi, Karus, Kudymov and others /2—5/)

Regional geophysical investigations of the territory of the USSR and of other countries are developing at great pace. Characteristic of these investigations is the complex use of various methods both for the study of deep geological structure and for the prospecting of various minerals by the most rational methods.

Geophysical investigations of the deep structure of the earth's crust are considered in ample detail in the paper of I. S. Berzon and P. S. Veitsman in the present collection.

The most extensive generalization of the complex of geophysical data for the purpose of original study of the territory was carried out in the Azerbaidzhan SSR (Kulikov /6/), in West Siberia (Agul'nikov et al. /7/), East Siberia (Savinskii /8/), southern part of the Volga-Ural oil-bearing province (Khramoi /9/), Ukrainian SSR (Chirvinskaya et al. /10/), Southwest Ukraine and Moldavia (Sollogub /11/), Central Asia (Borisov /12/, Godin et al. /13/) and many other regions.

In individual cases use was made of one of the geophysical methods for studying regional structure, e.g., seismic prospecting, as is done on the Russian Platform and in Central Asia (Godin et al. /13, 14/); or gravimetry, as used in the region of the Great Caucasus (Balavadze et al. /15/). As an example of more detailed study of regional deep structure we cite the work in the Western Kuban downbuckle by (Kozlov /16/), Southeast Turkmenia (Mashrykov, Fomenko /17/), and Central Kara Kum (Vol'vovskii et al. /18/).

Results which have been obtained in the development of a scientifically-based set of geophysical methods make it possible to carry out prospecting for various mineral types.

In regional investigations of ore-bearing regions, a combination of methods is used: aerial magnetic, gravimetric, seismic and electric prospecting. To determine structures and promising areas, a combination of aerial magnetometry, gravimetric prospecting, metallometry and hydrochemistry is used (Polyakov /19/, Miller, Solovov /20/, Krutikhovskaya et al. /21/).

In prospecting for iron deposits a combination of magnetic and gravimetric prospecting is used. In prospecting for copper-nickel ores — aerial magnetic and gravimetric surveying, electric and magnetic prospecting, etc.

A new rational combination and the corresponding methods of prospecting for rich iron ores have been developed in the regions of the Kursk magnetic anomaly (Pavlovskii /22/) and in iron-ore provinces of Rumania (Ionescu /23/; Stefănescu et al /24/). The attempt to map iron ores by means of the "Slingram" and "Turam" methods was effective (Frischknecht et al. /25/).

The use of a combination of geophysical methods in prospecting for oil-bearing structures has developed on a particularly large scale. Geological investigations on exploration and prospecting for oil in capitalist countries were carried out in 1961 by 846 crews (including 717 seismic, 96 gravimetric, about 20 electric and 8 magnetometric). In the USSR in the same year 850 seismic, 200 electrometric, 100 gravimetric and 16 magnetometric crews operated /26/.

The current methods of oil prospecting are based chiefly on the exploration of various structures (uplifts, salt tectonics, stratigraphic traps and others) to which oil deposits may be confined. However, great difficulties arise in explorations of deposits confined to weakly pronounced structure (for example, small dips). Together with this, the necessity to reduce the amount of drilling forced geophysicists to obtain data indicating the presence of oil in structures, i.e., to work out methods of prospecting for oil-gas-bearing deposits. The effectiveness of seismic prospecting for this purpose is shown in the works of Mirchink, Ballakh et al. /27/. In individual cases, an effective means of determining oil formations may be gravimagnetic surveying (Geyer /28/). Medovskii sees the physical principles of methods of estimating oil-gas-bearing capacities in the use of the differences in the absorption coefficients of elastic waves, and differences in the densities of the oil bed and of the enclosing rocks /29, 30/. Some American investigators consider geochemical methods promising; also radioactive gamma-ray-surveying (Roy Amalendu /31/).

The investigation of the possibilities of radiometry for direct oil prospecting has continued. In particular, the results of aerial gamma radiometry in the conditions existing in a number of regions are evaluated as positive (Dmitriev et al. /32/, Simin Dina /33/, Miller /34/, Merritt /35/).

The alternating electromagnetic field method is proposed for direct oil prospecting. The presence of an oil deposit creates a phase shift between the source field and the secondary induced field, which is due to the creation of an additional electric capacity by the deposit (Slattery /36/).

1. Economics and Productivity of Geophysical Works

The introduction of a new technique should in the first place be considered from the point of view of economic efficiency. The effect of raising labor productivity and the period of return of the investments in the introduction of a new technique should be taken into account. It should be remembered that in a number of cases, economical efficiency cannot be calculated, but the introduction of a new technique makes it possible to solve specific problems, replacing other types of geological-prospecting. Economic efficiency is also determined by labor organization (Banaš /37/) and productivity (Evdokimov /38/), after the introduction and use of the new methods in the complex of geological-prospecting. A comparison of the cost of the former with the new complex is made in a number of instances (Karpushin et al. /39/, Guzik /40/). The economics of geophysical methods particularly interesting to American specialists (Newfarmer /41/, Goldstone /42/, Kozlov /43/).

One of the effective ways of raising the productivity of geophysical observations is the use of aerial methods. Aerial magnetic surveying has undergone great developments (Glebovskii /44, 45/). It has raised the possibilities of improving the accuracy of surveying, and of recording the field in three components when the observations are carried out at several altitudes (Jenny /46/). This became possible owing to the use abroad of nuclear-resonance and rubidium magnetometers, as well as instruments with deviation compensators. In particular, the creation of the ferro-sounding self-orienting AM-13 air-borne magnetometer should be noted (Nikitskii /47/).

The fields of application of aerial surveying have been expanded. Aerial magnetometry was successfully used in prospecting for diamond bed deposits (Barygin /48, 49/), in the study of deep-lying structures of the terrestrial crust in Siberia (Bulina /50/), and in the southwestern part of the Pacific Ocean (Solov'ev /51/).

Aerial magnetic surveying was used in prospecting for iron-ore deposits in a number of regions (Kotlyarevskii et al. /52/. From magnetic surveying data it was found possible to trace disjunctive dislocations (Kronidov /53, 54/). The combined use of aerial magnetic surveying with other methods makes prospecting work less ambiguous. Thus, for example, its combination with aero-electrical methods gave positive results in prospecting for sulfide ores in Karelia and on the Kola Peninsula (Artamonov et al. /55/). In prospecting for rare-earth elements, it is used to advantage in combina combination with radiometry (Rybakov /56/).

Aero-electrical prospecting has proved its usefulness. Two modifications of this method have been worked out in the USSR. The first makes it possible to study the field of an infinitely long cable, the second — to use the induction method (Karandeev et al. /57/, Tikhonov et al. /58/, Mizyuk /59/). Recently the rotating-field method was proposed (Shaub /392/). Some variants of aero-electrical prospecting have been developed abroad. Most widespread is the method of recording the intensities of an artificially excited intermediate-frequency field (Gaither et al. /60/). A method based on the determination of the secondary component and of the phase angle between the primary and the total field on various frequencies is being used (Puranen et al. /61/, Shaw et al. /62/). Investigations were carried out dealing with raising the accuracy of aero-electrical prospecting by an alternating current and with the introduction of corrections for the variation in the mutual position of the generating and receiving frames (Suoninen /63/). An attempt was made to conduct aero-electrical prospecting observations from a helicopter (Shaub /393/).

Research is being continued to find the most effective means and methods of measuring gravity from the air. In particular, a new method was proposed for integrating gravitational anomalies (Paterson /64/); also for allowing for topography in aerial surveying (Chinnery /65/).

In the field of aerial radiometric surveying, the surveying technique, using measurement of the gamma-field by scintillation counters at two levels from the same airplane, is of interest (Glebovskii /44—45/). In the aerial radiometric method an important role is played by spectrometric surveying with radiation recording in two channels, which makes it possible to determine the ratio of the equilibrium radiation of uranium to the radiation of thorium (Smirnov /66/).

A device for aerial gammametry with automatic reduction in the counter readings for the flight altitude and for the flight velocity was proposed (Lee /67/). Methods were found for allowing for corrections in prospecting for radioactive ores under a forest cover (Matveev /68/).

Another aspect of raising the productivity in the processing and interpretation of geophysical data is the use of computers, both analog and digital. By using methods of reproducible recording, the possibilities of automation of interpretation methods were increased. Central interpretation bureaus have been created in the USA, where various methods of representing seismic recordings using certain methods of frequency selection, shifting, and grouping are practiced. Various methods of statistical and digital analysis are used (Michon et al. /69/, Bucy /70/). Much attention was given to the creation of analog computers for transforming seismograms obtained by the method of reflected waves into seismic sections.

In the first place, the principal ways of transforming seismograms into sections were considered. For this purpose, the introduction of kinematic errors for topography and for low-velocity range was programmed for automatic processing of seismograms and plotting of sections (Klugman, Lerner et al. /71—73/).

Numerous variations of the equipment for transforming reproducible magnetic recordings into seismic sections were proposed (Piety /75/, Klein et al. /76/, Williams /77/, Bucy et al. /78/, Musgrave /79/, Eisler /80/).

Digital computers are also used for plotting reflecting boundaries (Kántas /74/).

Highly promising is the use of equipment for the plotting of geological sections, on which boundaries of layers of different thickness and boundaries with different ratios of acoustic hardness are represented by different colors (Loper /394/, Palmer /396/).

To study the mutual correlation of seismograms, an analog seismic analyzer was created by means of which it is possible to find co-phase axes (Tullos et al. /81/). In the USA methods of primary processing of seismograms have been widely developed. In particular, very important is the use of devices for automatic reading of the travel times from seismograms (Burns /82/).

An analog computer has been developed for interpreting data of spatial seismic soundings, taking into account the curving of the seismic rays in the overlying layer. The computer determines the coordinates and spatial position of the reflecting element (Timoshin /83/).

Important also is the trend connected with laboratory transformation of oscillations on visible recordings into an electric current. In this case, the recording on a photographic film, unwinding from a drum, is searched by a photoelectronic device. Thus, by means of a coding device an analog recording can be transformed into digital form (Rykov et al. /84/). This was also accomplished by the firm E—ectrp Dinamic Instr. [sic] for the plotting of sections (by any of the three methods: amplitudinal, variable density and variable area /85/). Equipment was proposed for transforming the recording of seismic oscillations into coded digits for subsequent processing by a computer, (Unterberger /86/).

It is possible to automize the interpretation of vertical electric logging with means of computers. The basis of this interpretation is the selection of a master curve which has the smallest deviation from the experimental curve (Yukna, /87/). An instrument was constructed for measuring the apparent resistance for any value of K (the coefficient of the measuring equipment). The instrument works like a millivoltmeter with a circuit of an electronic autocompensator (Karandeev et al. /88/).

In radiometry, computers are being used for determining the relation between the radiation intensity and the lithology of beds.

In gravitational and magnetic prospecting, computers are used to calculate the derivatives of higher potentials and the reductions. A number of methods for mechanizing the processing of anomalous magnetic and gravitational fields have been found. In particular, it was found possible to calculate corrections for the topography, to perform integral transformation of anomalous fields, to plot the relief of a gravitating surface, and to determine the position elements of some bodies (Karataev /89/).

Computers are used for transforming geophysical fields (for separating gravimetric anomalies into local and regional). In this case, various interpretation methods can be programmed (Volodarskii et al. /90/).

The data on the south Minusin trough and on the Amur Zei depression have been processed in this way (Volodarskii /91/).

A computer for semi-automatic processing of magnetograms was built for the purpose of plotting graphs of the field intensity components (Blat /92/).

A method was proposed for solving two-dimensional gravimetric problems, based on the method of trial-and-error by thin layers. The method was tested on a computer (Shalaev /93/).

2. Seismic Prospecting

At the present time seismic prospecting is widely used for the solution of the most diverse geological problems, although the main part of the work by this method belongs to the study of structures in sedimentary formations. At the same time, seismic prospecting is solving more and more complicated problems, and the depth of investigation is increasing. This requires the development and use of new technical and methodical means.

Together with the method of reflected waves, the correlation method of refracted waves and high-frequency seismics has become widespread in recent years. The increase in investigation depth was made possible by the use of the method of deep seismic sounding. Significant results have been achieved in the development of the technique of marine seismic prospecting. The method of regulated directed reception and aerial spatial seismic soundings has begun to be widely used.

The main trend in the technical improvement of seismic prospecting is the use of intermediate magnetic recording, which in turn is responsible for the development of automatic observation processing means. The use in seismic prospecting of the method of acoustic logging (Karus et al. /94/) made it possible to obtain more accurate and detailed characteristics of the medium from elastic properties, which stimulated the development of the method of synthetic seismograms (Richard /95/). To obtain additional data by means of a section and raise the accuracy of seismic prospecting, new wave classes (in particular transverse and composite), as well as dynamical characteristics of different wave types are being used.

In the field of physical and theoretical principles, the investigators turn in in the first place to the establishment of regularities in the propagation of elastic waves in media of more complicated structures. Wave processes in nonhomogeneous laminated media, in beds having gradients of the velocity of seismic waves with depth, such as for example sandy-argillaceous rocks or ice, came under consideration (Thiel et al. /96/). In the case of such media the investigations of refracted waves is very important (Tseng Jung-sheng et al. /97/). Here problems concerned with the formation of reflected, refracted and head waves in the presence of poorly defined boundaries and transition layers have become important (Bortfeld /98/). This problem was mathematically treated by the contour integral method by Tsepelev /99/. Very important are the characteristics of the so-called zone near the initial point, i.e., the interference zone of the reflected and refracted waves (Gerveny /100/). For this, the character of the shift upon reflection and refraction of an elastic wave from a dividing boundary was investigated. The ratio of the intensities was obtained near the fronts of these waves (Dix /101/). A new approach to the calculation of the amplitudes of seismic waves in a stratified medium is interesting; it is considered as a system with definite transitional characteristics. Taking this into consideration and excluding transient processes in the seismic equipment, it was found possible to obtain the primary shift magnitudes (Kravets' et al. /102, 103/). Seismograms were statistically analyzed in order to determine the most probable reflections in stratified media for the purpose of studying the statistical properties of the velocities of longitudinal waves, and the reflection coefficients from experimental data, in order to determine methods for suppressing interferences, etc. (Agard /104/).

New regularities in the characteristics of head waves from curved seismic boundaries were obtained. Their kinematic and dynamical characteristics were studied (Voronin et al. /105/, Fedotov /106/). In the study of thin layers and wedge-outs the development of experimental methods of determining amplitude spectra of seismic waves, for the purpose of studying the functions of absorption amplitude spectra and the frequency-dependencies of reflection coefficients of longitudinal waves from thin layers, becomes important (Berzon /107/). The filtering properties of thin layers for stationary harmonic waves were studied, and methods are given for determining the effective attenuation factors of waves for a medium containing thin layers (Vasil'ev et al. /108/). A theoretical consideration of shifts in a medium containing thin plane-parallel layers was carried out by (Molotkov /109, 110/. The relative intensity of different wave types in these layers was also studied (Oblogina /111/).

Wedge-outs in deposits of the sedimentary type may at the same time be oil traps. In the first place such zones can be studied from definite properties characteristic of the reflected waves. Zones of this kind were studied in a number of regions, for example in the West Siberian lowland — Bol'sherechenskaya area (Kovalevskii et al. /112/). Wedge-outs were also studied by simulation (Kun /113/).

A combined seismic prospecting method, in which along with longitudinal waves other wave classes are used, makes it possible to obtain new characteristics of the medium. In this connection, the study of transverse and composite waves; methods of excitation and experimental study of their kinematic characteristics, have become of great interest (Puzyrev /114/). In this connection, the conditions of their formation and criteria of identifying transverse and composite waves were studied (Ratnikova /115/).

An experimental investigation of the dynamical characteristics of seismic waves in real media was carried out over a number of years at the Institute of Physics of the Earth (Berzon /117/). In the theoretical study of the dynamical characteristics of seismic waves use is made of the ray method — a method of approximate calculation of intensity near a wave front. In particular, this method recently made it possible to determine the variation in the intensity of waves propagating in anisotropic media (Babich /118/, Alekseev et al. /119/. The amplitude and frequency spectrum of seismic waves are used more and more in the interpretation of seismic prospecting data. The characteristics of the amplitude and of the form of the recording of reflected waves give information on lithological changes in beds. The attenuation of refracted waves makes it possible to form an idea of the thickness of the beds (O'Brien, /116/).

By analyzing amplitude spectra, it was found possible not only to separate interference waves, but also to determine the phase shift of interfering oscillations (Grin' /120/), to estimate the parameters of intermediate-thickness layers forming the reflected waves (Khudzinskii /121, 122/, Grin' /123/), to investigate wave spectra near the explosion, and their dependence on the elastic and absorbing properties of the rocks (Huang Jen-Hu /124/); also to determine the frequency composition of seismic waves corresponding to strong dividing boundaries (Vol'vovskii et al. /125/). It is important in this connection to determine the accuracy and reliability of the frequency analysis, as well as the possible distortions due to the limitation of the complete pulse and the analysis of only part of it (Gratsinskii /126/). Analog computers were used for the analysis (Khudzinskii /127/); and in addition, the spectral characteristics were also determined graphically (Averko /128/).

The method of ultrasonic simulation was used to investigate a large number of direct seismic prospecting problems, of which most important is the study of diffracted waves and of waves due to thin layers (Lavergne /129, 130/, Kun /113/).

In the simulation, bimorph media begin to be used, as well as perforated models, in which elastic waves form with a velocity depending on the averaged elastic properties and on the mean density of a laminated plate (this plate can be made of such pairs as: brass-dural, plexiglas-micarta, brass-iron, etc.), as well as on the system of holes in the plates, if perforated models are used (Samina /131/). For a wide-range recording of the oscillations, capacitance receivers and piezoreceivers with a damping device are used (Telezhenko et al. /132, 133/).

An automatic analyzer of ultrasonic oscillations was built making it possible to observe on the screen of an electron-beam tube the spectral composition of an oscillation arriving directly from the pickup unit (Obukhov /134/).

The raising of the interpretation accuracy of seismic field prospecting data is also connected with the accuracy of the determination of the effective, mean and layer velocities. Attempts are being made to use regularities in the variations of these velocities for solving structural problems (Urupov /135/, Gol'din /136/).

The study of the relationships between physicomechanical parameters may be the basis for the determination of lithological characteristics of rocks from seismic prospecting data. Correlations between elastic properties and density for some rocks of the sedimentary series were determined. For these rocks a linear dependence of the density on the velocity is observed (Martirosova /137/, Stetyukha et al. /138/). A correlation between the electric and elastic properties of a rock was established (Yashchenko /139/). Relationships between the porosity, the degree of saturation with a definite liquid and the velocity of elastic waves were established. It is found possible to differentiate porous mountain rocks saturated with different fluids according to velocity (Petkevich et al. /140/, Viksne et al. /141/).

Ultrasound has found wide application in the study of elastic properties of mountain rocks, the work being carried out both in laboratory conditions and in natural conditions — on exposures as well as in wells (Emelin et al. /142/). Acoustic methods were also used for studying the elastic properties of upper layers in engineering surveys (Koptev /143/).

Much material has been accumulated on the determination of the ratio of the velocities of longitudinal to transverse waves. This ratio varies in sedimentary rocks from 1.9 to 3.1 (Bulin /144/). In the study of elastic constants of mountain rocks the investigators pay attention also to Poisson's ratio. It was found that as the mountain pressure rises, Poisson's ratio somewhat increases. It was observed that the value of σ is largely influenced by the presence of quartz in the rocks, and that an increase in its content reduces the value of σ. It is noted that weathered rocks should be characterized by higher values of σ than preserved rocks (Lyakhovitskii /145/).

A series of experiments has been carried out on the influence of loads, high temperatures and water content of rocks on the propagation velocity of elastic waves, in order to establish the dependence of the velocity in rocks subjected to pressure both in laboratory conditions, and in conditions of natural mountain pressure (Volarovich et al. /146/). The largest increase (by 15—20%) in the velocities takes place when an isotopic pressure rises from 0 to 500 kg/cm^2. A temperature rise produces the opposite effect, but its magnitude is small. The effect of humidity differs, depending on the lithology of the rocks. Fissured rocks with low velocities have the velocity more strongly modified under pressure (Petkevich /147/, Ladefroux /148).

The mechanical properties can be studied by methods of statical mechanics — first in conditions of pure shear, and then passing to the study of prolonged strength taking into account processes of brittle breakdown and of plastic deformation (Rebinder /149/). The influence of metamorphism on the physical properties of rocks and minerals was found. In particular, this influence was studied for coal samples taken from different basins. The regularities discovered make it possible to determine the quality and rank of coal by logging, and, in particular, by the ultrasonic method (Toporets /150/).

Up to the present few experiments have been carried out on absorption and dispersion of elastic waves in rocks in a wide frequency range. More attention has been given to oscillations with frequencies of 2—100 Hz (laboratory studies) (Donato et al. /151/). An attempt is being made to determine the frequency-dependence of ultrasound absorption in rods (Rapaport /152/). An experimental study was carried out on the dependence of the absorption coefficient on frequency both in the pulsed and in the stationary regime (Howell /153/).

The necessity to penetrate to greater and greater depths faces seismic prospecting with a series of new problems. This required in the first place the finding of waves for increasing the energy of wave excitation sources (Hesche /154/, Krey et al. /155/). In order to reduce the intensity of interfering waves on the seismic recording, a combination grouping of the explosions and seismic pickups was tested (Kaneko et al. /156/). Problems of controlling the excitation of elastic oscillations, of raising the efficiency and selecting the radiation directivity of elastic waves draw increasing attention. Investigators attempted in this connection first to replace expensive explosive materials. Various types of shock devices are being used /157, 158/. In the form of a decreasing load, hydraulic impacters, etc., provide controllable excitation of soil vibrations in the frequency range 50—150 Hz (McCollum /159/, 160/). Here, storage devices become important in multiple recording (Voyutskii /395/). Devices which excite short explosive pulses in the ground and give harmonic oscillations with a smoothly varying frequency (20—80 Hz) which last several seconds are beginning to be used (Crawford et al. /161/).

Further search for waves for increasing the effectiveness of explosion grouping, for improving the directivity (Grudeva /162/), the efficiency and the variation in the frequency in the recording of reflected waves, is being conducted (Olszak /163/).

A new form of dependence of the amplitude of elastic waves on the charge magnitude was obtained (Ivanov /164/); $A = kP$, where A is the amplitude of the excited oscillations and P is the charge weight.

Seismic surveyors systematically turn to methods of grouping seismic pickups as a means of raising the effective sensitivity and separating out useful waves (Maiorov et al. /165/, Urupov /166/). New data were obtained developing the theory of interference systems — the grouping of pickups of pulsed seismic oscillations. In this case the Laplace transformation was used. As a result, a new technique of choosing grouping parameters is proposed (Timoshin /167—170/, Limbakh /171/, Bespyatov /172/, Kharitonov /173/). The advantages of grouping seismographs with a preassigned sensitivity distribution are shown (Valencio et al. /174/, Chichinin /175/). A systematic analysis of errors in grouping of seismo-pickups was carried out. It was shown that inaccuracies in the setting up of a group with respect to distances between the pickups and sensitivity, result in errors. Recommendations for raising the accuracy of the recording in the case of grouping are given (Gol'tsman, /176/).

Increasing attention is paid to problems of three-component recording, since this technique contributes to the collection of new data on the nature of different wave types, and to improved data interpretation, in particular in the case of observation in wells. New three-component installations are being built (Knothe /177/). The study of the character of seismic oscillations at internal points of the medium, has begun first in wells.

The method of regulated directional pickup has become an effective means of collecting and separating out different waves. Its possibilities for studying the fine structure of waves were shown by Ryabinkin /178/, Trorey /179/. A detailed study was made of the application peculiarities of RDP to the study of rough boundaries (Voskresenskii /180/). An analysis of the errors of RDP was made (Nakhamkin /181/). The RDP method makes it possible to increase the investigation depth up to ten kilometers in individual cases (Meshbei /182/). Its effectiveness was shown for many regions of the USSR (Trigubov /183/, Kasparova /184/; and it was found possible to perform, by means of RDP, an analysis of refracted waves (Dobrev /185/).

If the velocity variation is known from the data of acoustic logging, then by computation or by using analog computers it is possible to obtain the seismogram of the reflected wave. This seismogram comes out similar to the experimentally obtained recording of the same wave, which helps in understanding the wave picture on the profile along which the seismic observations were conducted (Dürschner /186/). To compare synthetic with experimental seismograms a special apparatus was built (Anstey /187/).

Synthetic seismograms are used for choosing a rational prospecting technique, and optimum filtration; by means of these an estimate of the probability of reflections can be made. They make it possible to establish stable correlation criteria for tracking of reference reflected waves over large areas (Delaplanche /188/, Jenner /189/). The use of synthetic seismograms creates premises for an analytic determination from field seismograms, of the velocity graph and the stratification for a given area with a view to obtaining more detailed information on the velocity structure of the medium (D'Hoeraene /190/). Despite the approximate character of the method of synthetic seismograms, these procedures have found practical application (Kunetz /191/, Baranov et al. /192/, Sengbush et al. /193/, Laherrere /194/).

Seismic investigation over water for the purpose of studying the structure of deposits under thebottom of water basins has increased. For this purpose use has been made of marine seismic prospecting in the usual version (excitation by means of explosions), as well as by underwater seismic profiling (excitation of oscillations by pulsed emitters). Observations were taken from the oceanographic ship "Vityaz'" in the Pacific and Indian Oceans. This made it possible to obtain sections and properties of the oceanic bottom, and to determine the thickness of the sedimentary layer (Kovylin /195—197/). Seismic surveying has also been carried out in the Arctic Ocean—Barents, Kara, Laptev seas (Kiselev /198/, Vartanov /199/).

Of methodical improvements, the new methods of suppressing reverberation should be mentioned (Grannemann /200/, Ghosh /201/). The use of a low-frequency version of marine seismic surveying makes it possible to increase the investigation depth to 5—6 km, and in individual cases up to 10 km. This is shown in the study of Mesozoic deposits under the bottom of the Caspian Sea (N. I. Shapirovskii et al. /202/).

A new method has been developed for underwater seismic profiling, using recordings of oscillations in a water basin, formed by spark dischargers, electromagnetic converters, etc. (Huckabay et al. /203—205/, Paterson et al. /206/, Smith /207/). In particular, under water structural geological mapping on Lake Erie (Canada) up to depths of 250 m was carried out by means of this technique. A layer of loose sediments and disjunctive-plicate structures was clearly distinguished in the bedrock (Paterson et al. /206/). Similar observations were conducted in Cape Cod Bay, USA (Hoskins et al. /208/), in the Shimabara Bay, Japan (Tyudzë et al. /209/).

The improvement of seismic-surveying equipment has continued. Problems of the theory of the seismic pickup channel were reconsidered, and the principles of the technique of calculation and construction of individual units (seismograph-amplifier-filter-galvanometer) were stated (Polshkov /210—212/).

Ways of raising effective sensitivity by building seismographs and amplifiers with low interference level (Warrick et al. /213, 214/), and building instruments for recording low-frequency oscillations (Rzewuski et al. /215/), were discovered. A trend towards portable instruments for seismic surveying is observed: e.g., portable seismographs /216/, oscillographs (Johnson /217/) and amplifier units using semi-conductors /218/. In engineering-geological exploration, the use of portable equipment by the method of first arrivals with one pickup has begun. In this case, the time of arrival is measured by means of a scaling circuit (Kaasa /219/, Catrakis /220/), and the excitation of oscillations is accomplished by means of impacts on a plate (Stam /221/). By recording refracted waves it has been successful in the study of the thickness of sedimentary deposits and the relief of bedrock (Hobson et al. /222/).

In recent years a series of new seismic stations with intermediate magnetic recordings, SSM-57, PPMZ, APMZ, 4M and others, appeared in the USSR (Fedorenko /223/).

At present, despite all the advantages of the equipment with magnetic recording, stations with oscillographic recording are still important. Slutskovskii's work /224/ is devoted to experience gained in the operation of such seismic stations, and an analysis of the quality of their work.

5. Gravimetric Surveying

Improvement in the methods of interpretation of potential fields still depends on a solution of a number of theoretical problems. One of the basic problems is the mathematical decomposition of the total field into components due to the influence of different geological factors. This decomposition can be carried out as follows: a) by averaging the observed field; b) by converting to another level; c) by using higher derivatives; d) by transforming the field (Nikol'skii /225/). In the final analysis, all these methods are based on the difference in the frequency-dependent properties of the graphs of the observed gravity values (Gladkii /226/). In this case, a detailed study of rock density remains the physicogeological basis of quantitative interpretation. Notable here, along with numerous works on the generalization of density characteristics in a number of regions, dependent on type, depth and age of the rocks, is also the establishment of the existence of layer-by-layer density zonality (Andreev /227/).

When analysing fields it is advisable to carry out a simultaneous analysis of gravitational and magnetic fields (Karataev /228/), to eliminate the regional field by integral transformation of the observed field and perform a statistical analysis, making it possible to determine the spectrum and amplitude of the regional field (Karataev /229/).

Various methods of separating local and regional anomalies were proposed (Fajklewicz /230/, Prakash /231/, Tsimel'zon /232/), one of which makes it possible to separate out the effects due to a large density difference (Moiseenko /233/). Separation of "low-frequency" field components, or rather, a smoothing of gravitational anomalies, can be accomplished by transforming the sequence of observed values into the most probable smooth sequence (Afanas'ev /234/). Regional fields are separated out by converting the initial field onto the upper half-space (Nikol'skii /255/): For this purpose special sets of master curves were set up (Klushin /235/ Tsuboi /236/, Solov'ev /237/. New computational schemes for analytic continuation of potential fields were proposed (Strakhov /238/), and the conditions of application of this method considered (Constantinescu et al. /239/). The principles of analytic continuation were used for solving the inverse problem of magnetic and gravitational surveying. The principles of the method were investigated (Strakhov /240—243/, Lapina /244/); and a method for setting up quadrature formulas also proposed (Strakhov /245/).

Higher derivatives of the gravity potential are coming widely into use. (Paul /246/). In particular it is shown that higher-order derivatives better represent small anomalous bodies which are not deep-lying (Shvank /247—248/, Lukavchenko /249/). For determining anomalous masses the horizontal attraction component in the upper half-face can be used (Sagitov /250/, Milcoveanu et al. /251/). Graphical methods for solving the direct and inverse problems of gravimetric surveying by the second derivative are proposed. In particular, these methods are suitable for two-dimensional models of arbitrary cross section, as well as for a half sphere and a vertical step (Martynova /252/ Tyapkin /253, 254/, Pavlenkova /255/). When working with instruments which measure the second derivatives of the gravity potential it is possible to estimate the peculiarities of the tectonic structure faster. This is shown in a number of examples (Kogbetliantz /256/).

It has been shown that regional gravitational anomalies may be connected with the relief of the basalt layer of the terrestrial crust and with the Mokhorovičič discontinuity. The study of the base and of its internal structure was successfully conducted by methods based on the theory of analytic complex functions.

It has been shown that small dipping structures in many oil-bearing regions are associated with a density variation, which is manifested in the form of small local anomalies. If the gravimetric accuracy is raised considerably, it is found possible also to reveal small-amplitude structures in the sedimentary layer. This was shown in the example of the survey in the Volga-Ural oil-bearing region by means of a GS-11 gravimeter (Nemtsov /257/). Highly specific problems were also solved: e.g., prospecting for reef structures (Ferris /258/), detection of karst zones (Ogil'vi /259/) and others.

Gravimetric instrument construction has developed in the direction of higher precision, construction of gradient meters and a search for means of measuring gravity in motion. A high-precision gravimeter, GAK 6-M, was built, making it possible to perform single measurements with a mean-square-root error of ± 0.06 mgal (Veselov /260/). A gravitational gradient meter using Oetvos's torsion balance was tested and gave good results. It is intended for measuring horizontal components of the gravity gradient to within $\pm 5-15$ oetvos and with a high output (Poddubnyi /261/).

Important in high-precision gravimetric observation is the thermostating of the instruments, for which precision thermoregulators were developed (Tulin /262—266/). New methods for adjusting and calibrating instruments are also proposed (Romanyuk /267—268/, Koz'yakova /269/). The GAL-P gravimeter was developed and tested for work on sailing vessels. By using a group of such instruments it is possible to measure g to within 1 mgal accuracy (Bulanzhe /270/). For the same purpose, gravimeters whose oscillating system has a strong damping were used. Methods were devised for processing data obtained in measurements on the sea by means of such gravimeters (Kuzivanov et al. /271/). Results of gravimetric measurements on a surface vessel are given (Grushinskii et al. /272, 273/, Gainanov /274—276/, Smirnov /277/). The possibility is shown of carrying out gravitational surveying at sea without anchoring the vessels, which makes it possible to conduct observations within short periods and place instruments at great depths (Gadzhiev et al. /397/).

A special problem in the exploration and prospecting for ore deposits arises in underground (mine) gravimetric surveying. Gravimetric and variometric measurements in underground mountain holes made it possible to carry out more reliable prospecting for ores, and to study the peculiarities in the micro-structure of ore fields (Mudretsova et al. /278/). Some problems concerning the relationship between variometric and gravimetric observations have been solved. In this connection, the causes of possible differences between these surveys are studied. They may be due to the distorting influence of relief, or to underestimation of anomalies in the vertical gravity gradient. In particular, problems involving the effect of relief are discussed in a number of papers (Dergachev /279/, Berezkin /280/, Lukavchenko /281/, Berezkin /282/).

4. Magnetic Prospecting

Magnetic prospecting acquired great importance in the study of ores. In this case, micromagnetic surveying was carried out (Lauterbach /283/, Conrad /284/, Ignat'eva et al. /285/). Aerial magnetic surveying has been widely used for regional investigations related to structural-geological mapping to different scales (Nikitskii et al. /286/). In the field of the interpretation of magnetic-prospecting data, as a result of the use of high-precision aerial surveying methods, mass determinations of the depth and relief of the upper crust of disturbing bodies have been made. One group of methods combines trial-and-error when using sets of master curves of ΔT, Z or H as well as of $\partial z/\partial x$ or $\partial^2(\Delta T)/\partial x^2$. The second group includes methods of determining the coordinates of the magnetic moment of the disturbing bodies. In this case higher derivatives of the magnetic potential are used, and the relationships of the functions ΔT, Z H in the case of direct and oblique magnetization of bodies are studied (Logachev /287/). The interpretation of magnetic-prospecting data is done in two ways: a) by comparing typical anomalies arising from a definite type of geological formation; b) by using methods of calculating the bedding and magnetization elements from observation data. For a more effective use of the first way, an atlas of typical anomalies, the geological causes of which are well studied, has been prepared (Logačev /288/). Attempts are being made to determine the direction of magnetization from the results of magnetic measurements. In this case the direction cosines of the magnetization vector of the whole body are determined from field measure measurements of the x and Z components (Tyapkin /289/).

Paleomagnetic investigations, intensively developing during the last 10—12 years, in addition to yielding to data of a general geophysical character on the history of the transformation of the geomagnetic field in different geological epochs and the motion of its poles (Creer /290/), has led to a new method for solving applied geological problems, in the first place the correlation of sedimentary rocks and the determination of absolute age of rocks (Janovsky /291/, Blundell /292/). Paleomagnetic data combined with lithologic-stratigraphic and paleontological data make it possible to carry out a stratigraphic subdivision of the sedimentary complex (Forsh /293/). Paleomagnetic data were used, for example, in the study of the tectonics of the basement of the West Siberian lowland (Karataev /294/). By means of the paleomagnetic method, the age of rocks in a number of regions was studied, for example the unfossiliferous red-colored layers of North Ural (Komarov et al. /295/). Paleomagnetic investigations were carried out on the igneous rocks of Georgia (Vekua /296/) and on rocks of Paleozoic and Mesozoic age in the Ukraine (Kruglyakov /297/). In the development of the physical principles of paleomagnetic investigations the study of the magnetic stability of rocks is of great importance. Such investigations were carried out by means of artificial rocks containing a stable component, which gave residual magnetization (Brodskaya /298/). Data on the possible existence of secondary magnetization of rocks owing to the penetration into them of ferrous solutions were obtained (Bidgood /299/). Highly important is the study of secondary processes which modify the magnetic properties of rocks. In particular it has been shown that titanomagnetite after oxidation at a temperature above the Curie point is transformed from paramagnetic to ferromagnetic (Kobayashi et al. /300, 301/).

A new type of magnetization, arising in a rock when repeatedly heated several tens of degrees in a constant magnetic field, was studied. Experiments showed that this type of magnetization, called cyclic, occupies an intermediate place between normal and ideal magnetization with respect to all magnetic parameters (Petrova et al. /302/).

It is observed that hydrostatic pressure reduces the residual magnetization of ferromagnetic components of rocks (Kume /303/). Hall and Heil observed a small, but constant, difference in the direction of thermoresidual magnetization in rocks cooled under pressure and without pressure. This apparently is connected with the internal anisotropy of the rock (Stotte /304/). A methodical consideration of the so-called viscous magnetization is given. It is shown that the relationship between the stability in time of the residual magnetization and its stability with respect to the effect of magnetic fields is not unique for different types of magnetization (Yanovskii et al. /305/). The variation in magnetization is largely affected by the time-varying effect of the surrounding ferromagnetic bodies (Neumann /306/). A method was used for determining magnetic characteristics, based on the recording of natural variation in the geomagnetic field. Ore deposits modify the amplitude and direction of the variation. Deposits which are good conductors may modify the dominant frequency of the variations. Methods are proposed for measuring the variations, based on the use of magnetic frames (McLaughlin et al. /307/). Kopaev et al. /308/, Gul'nitskii et al. /309/ have been successful in determining the integral value of the magnetic parameters of a rock.

The development of magnetometric equipment has tended towards the use of quartz systems in magnetostatic magnetometers and the building of improved models on the nuclear-resonance principle. Nuclear resonance magnetometers have been improved by raising their speed of response. In particular, such an instrument with a digit-printing attachment makes it possible to perform a measurement every 2 sec, to within $\pm 1\gamma$ (Rotshtein et al. /310, 311/). The firm Askania built a new type of a torsion Z-magnetometer with a measurement accuracy of $\pm 1\gamma$ in a very wide range of Z /312/.

5. Electric Surveying

Compared with others, electric methods have the most diversified series of applications. In recent years direct-current methods began to be replaced by electric surveying based on the use of alternating electromagnetic fields. However, such direct-current methods as two-way electric soundings in a number of cases give reliable determinations of structures in the sedimentary layer (Zagarmistr /391/). Most promising were the following varying-field methods: a) dipole and frequency electromagnetic soundings; b) build-up of the electromagnetic field; c) magneto-telluric sounding and profiling; d) amplitude-phase multifrequency measurements; e) induced polarization; f) piezo-electric; g) high-frequency prospecting; h) radio-wave sounding (Shirokov et al. /313, 314/).

Soviet electric prospectors show great interest and pay much attention to the development of a version of the method of frequency soundings, in which the field source is a grounded dipole or an ungrounded contour, fed by an alternating current with a frequency from hundreds of hundredths of Hz's A number of experiments (Van'yan et al. /315, 316/) illustrate the higher resolving power of this method compared with vertical electric sounding using direct current. The principles of the theory and the principal interpretation methods have been developed. The best results are obtained when a combination of amplitude and phase curves is used (Yungul /317/). In particular, it is found possible to plot the phase curve of frequency sounding from the amplitude curve. The phase shift can be expressed by an interval of the function of the field frequency and amplitude (Van'yan et al. /318/). In frequency electromagnetic soundings it is very important, particularly in work at great depth, to separate out the useful signal on the interference background. This is done by storing the signal on a magnetic drum and revolving it at a constant rate, which makes it possible to fit into the recording an integral number of revolutions (Khomenyuk /319/). When studying comparatively small depths (up to 0.2 km) the method of continuous frequency soundings is used, in which the frequency of the feeding current, received by an interference-free pickup, varies continuously linearily (Enenshtein et al. /320/). A variant of the method of electric prospecting, using an alternating current with a swinging frequency of 1 — 1000 Hz, was proposed. The variation in E/I as dependent on the frequency variation is determined /321/. Similar work, but using higher frequencies and intended for the investigation of accordingly smaller depths, has been successfully carried out in sulfide ore deposits (Astrakhantsev /322/). In the case of deep electric sounding both artificially excited fields and natural fields can be used. In Czechoslovakia electromagnetic frequency soundings were used for studying structures of the sedimetary layer (Bláha /323/).

The natural electromagnetic field was studied in a wide frequency range, and an attempt was made to obtain information from very large depths (up to several hundreds of kilometers) (Tikhonov et al. /324/, Wiese /325/). On the other hand, the method of magneto-telluric profiling has become widespread (Berdichevskii, /398/). A method of electric prospecting has been worked out based on the study of transient processes in a magnetic field (Kovalenko /326/). When using drilled wells, the electromagnetic method makes it possible to study the bedding depth and the configuration of ore by lowering an electrode through the well into the ore (Braekken /327/).

Similar work, but using a direct current, was done in the Urals (Sakovtsev /328/).

When induced polarization is employed, use is made of the method of mean gradients in vertical electric logging; in this case the study of chalcopyritic and gold ores at depths of up to 150—200 m was successful. The efficiency of the method is shown in the study of ore deposits in North Sweden (Sumi /329/).

The theoretical principles of induction low-frequency methods of ore prospecting have been considerably widened. A technique of simulating alternating fields of sonic frequency was developed, calculations for transient processes were made, and optimum frequencies for the study of ore bodies were selected. The possibilities of separating anomalies into ore and non-ore studies of the frequency-dependencies of amplitude and phase anomalies have been considerably broadened. The main object of the application of induction methods is the prospecting for conducting ore bodies (Yakubovskii /330/). The induction prospecting method was developed in two versions: a) the method of two loops, and b) the method of magnetic dipole profiling using several frequencies. A method of separating anomalies according to the character of the variation in the amplitudes and phases of the field components at different frequencies (in the range of 100—7000 Hz) is proposed. It is shown that characteristic peculiarities exist in this variation for ore bodies (Sheinmann et al. /331—333/, Hawkins /334/, Shaw et al. /335/). New models of electromagnetic equipment were built. A station of frequency soundings was created for high-precision amplitude and phase measurements in a wide frequency range (0.04—250 Hz) (Enenshtein et al. /336/). For measurements of the variations in the natural electromagnetic field in the frequency range 0.5—1000 Hz, equipment was built with a low interference level and with possibility of frequency selection of the field variations (An et al. /337/). For recording the last stage of the electromagnetic field build-up a special amplifier was built with an electromechanical converter for conversion of the low-frequency input signal into an alternating signal, in the form of rectangular pulses fed at a frequency of 550 Hz.

Methods based on the use of an alternating electromagnetic field find application in various ways: Magneto-telluric profiling was carried out in permafrost conditions (Gvizd' /338/) and multiple-frequency induction prospecting for a number of ore deposits has been successful (Bezruk et al. /339/); Electric methods have been applied to the study of the stressed state of rocks (Liogen'kii /340/). The method of induced potentials has been effectively used for ore prospecting. The method gave good results for ore-disseminated bodies (Komarov /341/, Siegel /342/). It was found possible to use induced polarization for determining reservoir properties (Marmorshtein /343/). The expediency of using the method of field build-up for the study of the relief of a crystalline base was shown (Bogdanova et al. /344/). Radiowave sounding methods found application in the prospecting for deep-bedded ore bodies (Petrovskii et al. /345/) in the study of uranium deposits (Bondarenko /346/).

In sea observation variants of electric surveying are used. By means of the undersea electric surveying station ERSM-57, built in the USSR, preliminary exploration of structures, further detailing of the properties of tested anticlines, and mapping profiling are carried out (Andreev et al. /347/).

In the development of alternating-current methods it was necessary to determine the active component of the specific electric resistance as dependent on the current frequency. For this purpose, an electrothermal device was used. It was shown that the value of R decreases with increasing frequency for rocks of the sedimentary type (Ivanov /348/). Particularly important has become the study of absorption of electromagnetic waves in various rocks. The dependence of wave absorption on the conductivity and other electric parameters was studied. The variation in the attenuation of these waves with frequency was examined by Dokoupil et al. /349/. The anisotropy in the electric properties of rocks was also studied by Dobrovol'skii /350/, Stacey /351/.

One of the most striking examples of an efficient use of new electric characteristics of rocks was the development of the piezo-electric method (Volarovich et al. /352/). The piezo-electric effect of a quartz vein, lying in a piezo-electrically neutral rock, was measured under laboratory conditions. The piezo-electric effect under quartz and pegmatite veins in natural conditions was then investigated, and the magnitude of the effect due to such veins was determined (Parkhomenko /353/). A study of piezo-electric effect on the passage of seismic waves dependent on the medium's parameters and on the frequency of the excited oscillations was made by Kumazawa /354/.

6. Radiometry

The presence in rocks of some chemical elements can be determined by means of irradiating a sample by neutrons. In this case induced radioactivity is emitted. From the half-decay period and from the energy, information on the composition and content of the elements is obtained (Cabell /355/). Activation analysis has undergone considerable development. With this method, using special screens, the following elements are determined: aluminum, silicon, manganese (Glasson et al. /356/), thorium (Cherdyntsev et al. /357/), tungsten (Abdullaev et al. /358/). Facilities for analyzing samples of lithium, boron and other elements were devised (Ostroumov /359—360/). A polonium-beryllium neutron source and neutron counters of the scintillation type with a photomultiplier are employed employed. Irradiation by electron accelerators, and also by gamma-rays from Sb^{124} in the determination of beryllium, was used (Egorov /361/, Sen'ko /362/, Mezhiborskaya /363/).

A study of the density and composition of rocks and ores was recently carried out by the method of scattered gamma-radiation. In particular, the method of selective gamma-ray logging was used in antimony ore deposits. The advantages of the method were shown compared with methods of direct density determination (Balashov et al. /364/). However, the presence of lined joints and cavities introduces serious errors in density determination by this method. A model study of this effect was made Polak et al. /365/). Determination of densities from scattered gamma-ray-radiation was made both under laboratory and natural conditions (Nedeljkovic /366/).

By means of a scintillation counter, recording alpha-particles, it is possible to determine the concentration of radon and thoron (Lenin /367/). A scintillation counter can be used for beta-radiation recording in analysis of beta-activity of low-weight powdery samples (Zaitsev /368/). The gamma-radiation spectra of uranium ores with a U content from 0.04 to 1.11% were investigated by means of a scintillation spectrometer with a NaI crystal (Troitskii et al /369/).

Japanese investigators did a radiometric survey by vehicle in various regions of their country. Ore deposites, carbon and other deposits were investigated (Sano, Kharikava, Udzine, Khosyuno, Kandzumi, Nagakhama, Sugiyama, Nakaya, Kharada and others /370—388/). Radioactive prospecting has begun to be used in prospecting for deposits of nonradioactive minerals. The fact used here is that a number of deposits of rare earths — tantalum, niobium, phosphorites and others — contain some amount of accessory radioactive elements. On the other hand, radiometry is used as an indirect method of discovering non-radioactive minerals (Evstrakhin /389/, Lizanets /390/).

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EXPLANATORY LIST OF ABBREVIATED NAMES OF USSR INSTITUTIONS, JOURNALS, ETC., APPEARING IN THE TEXT

Abbreviation	Full name (transliterated)	Translation
AN SSSR	Akademiya Nauk SSSR	Academy of Sciences of the USSR
VMO	Vsemirnaya Meteorologicheskaya organizatsiya	World Meteorological Organization
NIAK	Nauchno-isslodovatel'skii Institut Aeroklimatologii	Scientific Research Institute of Aeroclimatalogy
MOV	Metod otrazhennykh voln	Reflected Wave Method
KMPV	Korrelyatsionnyi metod prelomlennykh voln	Correlation Method of Refraction Waves
MGGS	Mezhdunarodnyi Geodezicheskii i Geofizicheskii Soyuz	International Geophysical Union Association
GGO	Glavnaya Geofizicheskaya Observatoriya	Main Geophysical Observatory
TSIP	Tsentral'nyi Institut Prognozov	Central Forecasting Institute

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